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CHARACTERIZATION OF AIR PARTICLES GIVING FALSE RESPONSES WITH BIOLOGICAL DETECTORS

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CHARACTERIZATION OF AIR PARTICLES GIVING FALSE RESPONSES WITH BIOLOGICAL DETECTORS

FINAL REPORT
June 1972 Through 30 April 1975

by

Richard E. Putscher
Walter C. McCrone

July 1975

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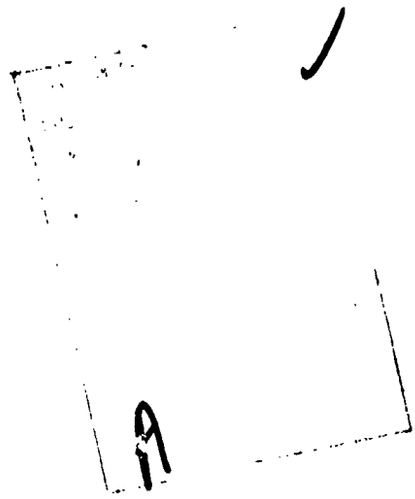

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Particle Atlas	Cyclone particle separators

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A comprehensive selection of air background particles representing 13 categories and a total of 552 different substances were tested for "alarm-like" responses in the chemiluminescence biological detector. Biological particles were most active in these tests and were also implicated as the cause of false alarm responses by the detector in open air tests upon examination of samples collected at the time of the alarms. Methods for eliminating detector responses to biological background were studied with major attention being given to separating biological aerosol from background particles by

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selective deagglomeration of the aerosol particles and separation of the "deagglomerates" from intact background particles. An experimental deagglomerator effectively reduced the size of aerosol particles with minimal breakup of pollen grains or spores. Cyclone separators were optimized for maximal retention of intact biological background and maximal passage of deagglomerated aerosol particles to provide a potentially practicable solution to the ambient background problem.

PREFACE

The work described in this report was authorized under Project/Task 1W662711AD34-02, Physical Defense Against Biological Attack, Detection and Warning Investigations. The technical studies in this contract were begun in June 1972 and were completed in April 1975.

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CHARACTERIZATION OF AIR PARTICLES GIVING FALSE RESPONSES WITH BIOLOGICAL DETECTORS

I. INTRODUCTION

The chemiluminescence (CL) detector system when used in field tests has periodically yielded alarms from materials not of interest. The goal of this contract effort was to identify such nonbacterial types of airborne materials that can result in positive detector responses and then subsequently to select methods for eliminating such unwanted responses or employ separation steps to eliminate the particulate substances causing alarms.

A three phase research program was conducted to accomplish the objective of the contract.

The first phase was the systematic evaluation of 552 representative substances divided roughly into 13 categories. These samples were taken from a reference set of particle standards representative of atmospheric contaminants used in the preparation of the Particle Atlas[1] recently published.

The second phase was a study of procedures used to eliminate detector responses from unwanted particles. Different washing procedures were tried and checked to see what their effect was and in addition what some of the contaminants were that were present.

The third phase was a study of separation procedures in the airflow system — using size selectors and cyclones. The final step performed was impacting particles directly onto the moving tape from the outlet of a small positive-pressure-flow cyclone.

II. RESEARCH PROGRAM

A. Systematic Evaluation of Reference Particles

The chemiluminescence (CL) detector was installed in our laboratory early in the program by Dr. Lloyd Graf and Allen Brumbaugh of Edgewood Arsenal and was used successfully in testing the 552 different samples from our Atlas Particle register. This evaluation was done by making minor mechanical changes in rerouting the film tape to permit direct application of particles rather than using the normal airflow impingement system. In this manner all of the different samples were tested with little or no possibility of cross contamination in the air system. Positive responses, or readings on the recorder in excess of 10 mv were considered as positive responses.

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1. The Particle Atlas, edition two, by W.C. McCrone and J.G. Delly, 973.

A summary of the particles tested is shown in table 1, appendix A. The details of the various individual particles are listed in two progress reports covering the period September through December 1972. In table 1, the particles are classified into 13 groups of substances with the numbers of materials tested in each group, and the number and percent of positive responses. Overall 25% of the particles gave positive responses. However, when divided into alpha (α) and beta (β) broad groups shown below the main portion of the table, we observe the alpha group representing biologicals, natural and man-made fibers and hairs, fertilizers and food products gave particles in which 67% showed positive responses. The beta group represented rocks, minerals, abrasives, catalysts, cements, cleansers, detergents, metals, polymers, industrial dusts, combustion and miscellaneous products. In this group only 6% of the particles showed positive responses. Table 2 lists all particles giving a positive CL response.

1. Effect of Sample Size

It is important to know the sample size required to obtain a positive response; if an excessive number of particles are needed for a response interference by that substance can be ignored. For example, if 50 bone dust particles in one extractable air increment ($\cong 100\ \ell$) were necessary for a positive response, interference by bone could be ignored because no such atmospheric contamination by bone dust can be visualized.

It is also obvious that the effect of particles is additive; if 20 pollen grains from 20 different plants are present they will behave essentially like 20 grains of the same pollen. In fact, a positive response could result under actual test conditions through the additive effect of several substances each present in subthreshold amounts. In nearly every case, we used a very large amount of sample in screening the Particle Atlas samples. If 500 particles were required to give a positive response, and if the particles are so rare no ambient dust sample can be expected to contain more than 5 particles, then that substance can be regarded as negative in response. To check this effect we tested 2 fiber samples that showed high response in the luminescence detector. The effects observed are shown in table 3. These two substances, feather and silk in quantities equivalent to less than 5 mm of fiber length would probably not show a positive response.

In the testing program very large samples of each substance were used, probably 10 to 100 times the amount that could ever be present in an actual sample. This means that many observed positive responses (less than 10 millivolts) would undoubtedly be negative in practice. In other words, the amount of any given substance must exceed a certain threshold before a positive response would result. This threshold must vary a great deal from substance to substance and must be higher than the expected atmospheric levels for most of those tested — although perhaps not in combination with other substances present.

In testing conducted there were indications that contamination may also be a factor. Particularly, when a fingerprint produces an off-scale response one suspects that fibers, if finger-handled, will also give a strong response even if inert by themselves. Most fiber samples will have been finger-handled at some stage before our testing.

The data obtained shows we may forget most inorganic substances, at least the insoluble ones, e.g., most minerals. Any of the inorganic substances which showed positive responses are most likely contaminated; even so, we obtained only 6% total positive responses. Most substances testing high were either organic substances or good absorbers of organic substances, and therefore easily contaminated.

The procedure used to put known quantities of material on the tape for testing involved cutting out a 1/4 x 1/8 inch rectangle of the film tape around a sprocket hole. This small bit of tape was then applied to the sticky film tape where the sprocket hole formed a small sticky area on which particles could be placed using a tiny spatula. The number of particles so placed on the tape were then counted microscopically. The results obtained from several experiments are shown in table 4, and also graphically in figures 1 through 3. Qualitatively, alfalfa, cottonwood and sugar maple pollen show about the same surface area response. Cottonwood pollen has the highest response.

Since biological particles as a group act collectively, it is very easy to exceed the response threshold in ordinary air samples. Inorganic particles, unless they act as carriers, will in general be negative. If soluble, they will give a positive response if they contain active ions such as cobalt, iron or iodine.

2. Effect of Particle Size

The target particles for CL detection are small <1 μm to several μm. It is fortunate that most particles sounding a CL false alarm are larger than this. Most pollens are >20 μm. Only some spores measure <5 μm. We will see later that size differentiation is a possible and perhaps the only possible separation procedure available to us. Table 5 shows the sizes of representative particles.

3. Sensitivity of CL Detector

It is rather difficult to make good quantitative measures of the sensitivity. However a sensitivity series was run using Lamb's Quarters Pollen. This is shown in table 6. Most of the variation observed is due to the covering of one particle by another and by loss of sample before the wash step. Considering these various things and the plotting of the data one can say that very approximately a Lamb's Quarters Pollen grain gives a deflection of 10 mV.

In table 7 the effect of some inorganic acids and ammonia are shown. Of the four, only ammonium hydroxide and sulfuric acid show some response and it is possible that some splashing was obtained from the sulfuric acid.

B. Washing Particles

1. Washing of Samples

A number of substances giving a high positive response were washed to remove surface absorbed material and retested. Many such substances were tested and table 8 gives some representative results. We found it quite necessary to completely clean the tubing and connectors frequently to be able to maintain a zero baseline between samples. Obviously, some particles collected in the system at some point were then continued to be extracted and continued to give positive responses. On one occasion a dried blood sample gave a tremendous background for some period of time (it almost required rebuilding the apparatus).

Later, a more effective washing procedure was developed. Particles on a membrane filter were washed successively with soapy water, distilled water, ethanol, chloroform and hexane. Most, if not all, of the material causing CL detection is soluble in these wash liquids (table 9). Since CL sensitive material could be extracted, it seemed logical to analyze this material and see what functional groups were responsible. Several substances available in quantity were extracted with water, ethanol, chloroform and hexane. The extracts were centrifuged or filtered to remove particles and evaporated to dryness on salt plates for infrared spectroscopy. Blanks were also run for each solvent, repeating the procedure except for the presence of the biological substance. The infrared spectra were studied and the results are condensed in table 10. The various extracts are shown in the upper portion and the characteristic peaks and functional group assignments in the lower portion.

Usually, several of the bands appear in each spectrum. Fatty acids and glycerides were found to be the main constituents. Two spectra, one on cottonwood pollen directly gave hydroxyl and carboxyl absorption in the unwashed but not in the washed sample. The results confirm that the substances found in the extract are, indeed, present in the pollen grains. The compounds involved are fatty acids and their di and tri glycerides with some unsaturation. These are very common substances and help to explain the fact that so many substances give positive CL detections.

2. Sensitivity of the CL Detector to Light

On one occasion the detector was wheeled outside on a clear, sunny, but breezy day. The detector response immediately rose to a high value which was maintained for over and hour. This response was not due to

particles on the tape. After some time the possibility of an effect of sun light was considered and the photomultiplier tube was covered with a black plastic bag. The response was then considerably reduced but not eliminated. Most of the remaining background was eliminated by the installation of black tubing over the liquid feed lines carrying the particle washing fluid.

In other tests made using the small cyclone (T-1B) outlet to feed the tape impactor, the detector response is given for two sets of runs made from outside air collections (table 11). In these tests the tape was stopped and the air sample impacted on one spot for the time interval indicated in table 11. Following the detector response tests, the tape portion for the 60 sec. sample of run 1 was examined microscopically and found to contain the following types of particles:

poliens	calcite
starch	quartz
plant hairs	iron oxides
fungal parts	oil soot
trichomes	incinerator flyash
insect parts	power plant flyash

The detector system was modified to give a steady baseline outdoors with filtered outside air through the impactor and with the expected response on introduction of test aerosol. The system was also fitted with a flowrate meter and manometer for measurement of pressure drops. An automatic tape marker was also installed to be activated whenever a positive response was obtained. In this way we could leave the detector operating unattended and recover the tape corresponding to a positive response for later microscopical study.

C. Backgrounds and Control Samples from Edgewood

Early in the program we received 9 control and background samples from Edgewood. We also sampled the dust in the shipping container because the 7 samples were not adequately protected from contamination by this dust. These samples were examined by light microscopy and particles found are shown in table 12.

The July 12 particles shaken from Edgewood Arsenal plants contained at least 3 kinds of particles which were stained by the partichrome process. Two of these were identified as epithilial cells and fungus, both of which were stained lightly. The third heavily stained species, consisted of isotropic flakes with angular outlines as of a resinous material which had cracked apart. High powered examination at 1250X revealed other stained particles, some of which are undoubtedly fungal parts. The floor sweepings were surprisingly free of fibers.

The 7 samples received by mail were heavily contaminated by the dust present in the shipping container, especially by fibers. The particles found in the shipping container were calcite and paint spray which were also found in the July 12 plant sample which had no contact with the container. Such samples must represent the normal Edgewood background. Unfortunately, the 7 samples contained few particles not also present in the container dust, so they are not very useful in showing the background they were intended to represent. A cleaner shipping method was agreed upon. The amount of fungus found in most samples was considerable. It was not certain however whether it represented a normal background.

Tapes both from our sampling and from Edgewood tests were examined microscopically. The tapes were taken before, during and after alarms. The alarm tapes all show high counts of biological material, mainly spores and pollens. The controls show smaller amounts of the same substances. The data for these various tapes are shown in table 13; counts are given per square mm for biological and flyash particles on these tapes. Most of the biologicals are pollens but there are also mold spores, and other plant debris. The flyash is nearly all from incinerators or open trash burning.

D. Particle Aggregate Reduction and Size Selection

1. Aggregate Reduction

It is known that airborne particles can be shattered by impaction at high velocity on a hard surface. Particles vary considerably in the energy needed to shatter them. The kinetic energy needed to effect shattering is furnished by the particle mass and velocity. Larger particles shatter most readily but there is for every particle, a threshold impact velocity below which it will not shatter. Most agglomerates are more easily broken up than equivalent mass homogeneous particles.

We propose to break up agglomerates of biological organisms by impaction. The velocity of impact is to be high enough to deagglomerate the organism cluster but not high enough to break up large homogeneous particles. The schematic of such a particle aggregate size reducing system is shown in figure 4.

Particles must impact on a small diameter convex surface to avoid buildup of materials. Air enters the unit from the left, carries the small particles around the end of a polished 120° cone and out the exit tube. Larger particles impact on the cone and bounce off into the air stream either intact or broken into smaller particles. A rod on the end of which is the cone can be moved in and out through an O-ring seal. It can take any position from closure of the entrance to flush with the back wall. Figure 5 shows the crossection and photograph of the completed unit.

Two variables were controlled; flow rate and gap. An extensive series of tests were made using aggregates of limestone particles. Single particles ranged from 1 through 20 μm with aggregates up to 100 μm. A representative set of data is shown in table 14 and indicates that the deagglomerator does work. There were, however, some aggregates of the smaller particles up to 6-7 μm which have not been reduced to single particles. There is also the fact that the equivalent aerodynamic diameter of biological particles is about 30% greater than the diameter of calcium carbonate.

A representative set of data to show the effectiveness of the deagglomerator was also performed on the SM particles. This is shown in table 15. In this case the SM particles were impacted directly on the tape for counting. Also, this table shows the results of using a modified deagglomerator in which the velocity of the particles striking the cone was increased by gradually degrasing the diameter of the entrance tube as in a venturi tube. The deagglomerator with a 1 mm opening nearest the cone was spaced about 0.3 mm from the cone. The flow rate in the selector was 20 ℓ/min. in the fine particle exit and 800 mℓ/min. in the coarse particle outlet.

In the testing of the deagglomerator and the size-selectors it was found that both require high flow rates (not less than 10 ℓ/min).

2. Size Selectors

It seemed to us that the only possible parameter we could use to separate active pathogens from normal atmospheric dust was particle size or, better, particle mass. Most biological particles will give a positive CL response but most naturally occurring biological particles are ≥ 5 μm whereas, at least, a substantial fraction of the pathogens are ≤ 5 μm. We felt that if the ≥ 5 μm fraction is not removed before the CL detector false alarms are certain to occur. We realized that, as used, there would always be a high weight percentage of pathogen in the ≥ 5 μm fraction hence elimination of that fraction would drastically lower the sensitivity of CL detection. To compensate for this we decided to try to break up the pathogen aggregates in order to increase the <5 μm fraction. Once the particle agglomerates are broken up (and without breaking up other large single particles) an inertial and/or cyclone separator could be used to eliminate the larger size particles and most, if not all, false alarms.

A size selector has been designed based on inertial separation. Figure 6 shows one design using a slotted aperture in the aerosol flow pattern. The slot should improve the efficiency of the selector. This selector can be used to separate fine from coarse particles. By choosing the proper airstream it can be made to reject coarser particles rather than fine ones. We have used it in this way because most interfering particles are ≥ 5 μm. The finished size selector (Mark I) is shown in figure 7.

There were however many variables to study, e.g., flow rate, gap between slots, division of flow through and around the exit slot. Many runs were made to test these variables with the best representative runs shown in table 16. These data show that a spacing less than 4 μm or greater than 11 μm between the two selector slots is best for the isolation of large particles.

We were not, however, satisfied with the reproducibility of these data and constructed a second size selector (Mark II). This unit has greater flexibility and is better constructed. (See figures 8 and 9). Before incorporating this selector, the overall apparatus was rebuilt to operate at 100 liters per minute with about 6-8 ℓ/min through the slot of the large particle exit. Figure 10 shows data for this selector operating at 100 ℓ/min and at 200 ℓ/min. The particle size data for SM as received are [illegible]ated SM feed; the horizontal axis gives particle diameters in μm and the [illegible]l axis gives number of particles. Samples were taken at the large particle exit; the data show that the 100 ℓ/min flow rate was best.

Additional data at 100 ℓ/min is given in table 17 to show the effect of slot separation in the selector. The most effective separation for the Mark II is in the range of 6 to 14 mm for removal of large particles.

E. Cyclone Separators

1. Cyclone T-1B

Unfortunately, the data for the size selectors investigated was far from the desired qualitative and quantitative separation of large particles. This dictated construction and testing of cyclone separators.

A small cyclone T-1B; (figure 11) was constructed in our instrument shop and installed in the CL test unit immediately before the tape impactor. Because of it's small diameter, the flowrate for separation of small particles is very low. In the investigation at the time we slowed the tape and the solution flowrates to compensate for this. The T-1B cyclone was installed, calibrated and used in an air sampling program. It functioned very well and any size threshold from 1.6 to 12 μm particle size could be set by controlling the flow rate. For example, at a flow rate of 3 ℓ/min only particles smaller than about 3.5 μm in diameter were impacted on the tape.

We have had most of our experience with 3 cyclones, T-1B and the T-2A, and T-3B, whose characteristics are shown in figure 12. These curves show that in order to attain a particle size cutoff at 4-5 μm of biological particles with cyclone T-1B a flow rate of about 5 ℓ/min is required.

To calibrate the T-1B cyclone an air suspension of calcium carbonate was fed to the cyclone and the particle size of the particles on the tape was measured corresponding to each of a range of flow rates (table 18).

Sixty of the largest particles were measured using a calibrated ocular micrometer as a measure of the maximum size particles collected. The rotameter was calibrated by a standard gas collection procedure and the size data measured for calcite (density = 2.75) were recalculated for bacteria (density ca 1.15). Both sets of size data are plotted in figure 13. The particle sizes given in table 18 are the diameters of spheres equivalent in volume to the largest particles observed. Photomicrographs were also taken of the particles on the tape at several representative flow rates (figures 14-18). At the magnifications shown, 1000X, 1.0 μm = 1.0 mm.

The CL test unit with cyclone T-1B was operated with outside air at a variety of flowrates. Only at the lowest flowrates (largest particle on the tape) did we observe a positive response. A number of portions of tape were cut out before, during and after alarms. A smaller number of similar portions of tape were received from Edgewood. All of these tapes were examined microscopically by placing the tape section particle-side up on a clean microscope slide, covering it with a clean cover slip and adding a drop of n_D = 1.515 immersion oil by capillarity. The individual particles could be readily identified using crossed polars, ordinary light or reflected light at magnifications up to 1000-2000X.

We attempted to make counts of active particles per cm^2 of tape, but with only qualitative success. The alarm portions did, however, show significantly more biological and flyash particles than the controls. We also tried to relate the particle count to the response height on the chart paper, but found little relationship. This, we feel, is due principally to the alarm often being caused by a splash of pollen or flyash which we may miss under the microscope. In some cases, we found the adhesive layer to be discontinuous or even absent. It was our experience that the adhesive level in the reservoir needed to be watched carefully. With the cyclone in the air sampling path we recorded alarms only on two occasions when the flow rate was set to permit up to 10 μm particles to impact the tape, and a dense cloud of fungal debris was fed into the air inlet. One of these tapes subsequently gave a count of 1250 biological particles / mm^2. (The CL response was full-scale and remained so for four minutes.)

Although we were testing with only 1-2 ℓ/min of air we felt that at this stage it was more important to test the particle size effect, and see if we could set an effective particle size limit for the sampling system. Furthermore, this system would allow testing to determine if enough of the normal atmosphere was excluded to prevent many false alarms and still include enough of the target particles to effect an alarm. We feel that flowrate control is adequate to control particle size. Furthermore, the evidence indicates that particle size control is sufficient to prevent false alarms due to normal atmospheric particles while allowing SM and other pathogens to be recorded as alarms.

Using this cyclone with the somewhat negative pressure of the CL system to impact particles on the tape allows some air leakage to occur at the tape zone. This is a disadvantage which may allow outside unfiltered particles to reach the tape, and also causes difficulty in making accurate air flow rate measurements. Little evidence due to leakage was observed in the series of runs made with the limestone particles, but it was thought desirable to operate under slightly positive pressure, if the apparatus would permit.

A second consideration is the particle size distribution of the SM test substance. When used and passed through the "Continuous Aerosol Concentrator"*, the size distribution is modified and a high percentage of the particle sizes from 1-3 μm are attenuated much more than the 4-8 μm sizes. In table 19 we show as background information the particle size data for SM before and after the concentrator. Also shown is the effect of the concentrator and deagglomerator on the SM particle size distribution. In figure 19 the same information is plotted graphically.

We have examined the SM particles by scanning electron microscopy with results as shown in figures 20-23. Typical aggregates of SM are shown in 20 and 21, an aggregate of nutrient (?) in 22 and individual SM as deposited from a drop of water in 23.

2. The Aerosol Concentrator

The aerosol concentrator is a very efficient device for the isolation of larger particles (table 20, figure 24). Operating on SM at a 10 ℓ final flowrate it collects 19.2% of all particles entering the unit, 54.8% by surface area, or 76.9% by weight. Our work indicates that we must collect only <5 μm particles to avoid interference by other innocuous biological particles. This further reduces the percentages of usable particles to less than 15 (by number), 30 (by surface) and 24 (by weight). This is equivalent to something less than 150 ℓ sample by number, 300 ℓ by surface and 240 ℓ by weight but with the particles in only 10 ℓ of air.

To eliminate the coarser (>5 μm) particles we need a size selector or cyclone to eliminate >5 μm particles. The choice is shown in figure 25. It would appear that we should keep the aerosol concentrator in spite of its low efficiency for fine particles because it does concentrate all particles in a much smaller volume. In other words, 15% (by number) of the <5 μm particles in 1000 ℓ is more than 96% of the <5 μm particles in 100 ℓ.

3. Cyclone T-3B

It was then decided to test a high volume flow cyclone such as the T-3B in order to evaluate its effectiveness in recovering more fully the 1-5 μm size particles. It was anticipated this cyclone should have a sharp

*Brumbough, A.D. and Mumford, S.A., U.S. Patent 3,731,464

cut-off at about 5 μm at a flow rate somewhere in the range of 100-200 ℓ/min. The T-3B cyclone was then constructed and submitted to testing. Figure 26 shows an upright view of the T-3B cyclone and the shop drawings. At flow rates of 300 ℓ/min and above, it was shown to be very effective in removing most of the particles above 5 μm (table 21). Data were collected over the range from 100 ℓ/min to about 450 ℓ/min. Above 400 ℓ/min the cyclone box collects most of the smaller particles even below 5 μm. This is indicated by the fact that few particles can be obtained on the glass slide inserted in the sampling stream. For optimum performance and separation it was found this cyclone should be operated in the flow range of 200 to 300 ℓ/min.

This large cyclone can be very useful if such a high flowrate is desired or required because separation is quite effective.

Note that at high flow rates the particle size of the product collected is about the same as that present in the dry SM powder feed except for some removal of the 5 μm and larger particles. A reasonable separation occurs in the 230 ℓ/min run also. The test made at 100 ℓ/min indicates poor separation with no particles collected in the cyclone box due to the low flow rate.

4. Construction of the Smaller T4 Cyclone

The T-3B cyclone required a higher flow rate for good performance than the desired air flow rate of 100 ℓ/min. A new cyclone was therefore constructed in which the upper cylindrical portion was about one-half the diameter of the T-3B unit. In addition, the upper cylinder portion was extended somewhat. This is shown in figures 27 and 28. The inside walls were highly polished to minimize any tendency for the physical collection of particles on the inside wall.

5. Evaluation and Testing of the T4 Cyclone

The T4 cyclone was then tested with the SM powder over the air flow range of 40 to 100 ℓ/min. The particle collector slide was placed in the outlet stream on a by-pass in which about 12% of the air flow was by-passed through the collector at an air flow of 100 ℓ/min and about 10% of the air flow at 40 to 50 ℓ/min. Table 22 shows the results of the first series of tests.

At flow rates below 45 ℓ/min there is very little collection of $\geq$5 μm sized particles observed in the cyclone pot, whereas, at 100 ℓ/min and over the cyclone box collects most of the particles even those below 5 μm. Since we want low losses or high collection efficiency for the particles <3 μm the optimum flow rate is in the 50 to 80 ℓ/min range, with the best flowrate estimated to be 60 ℓ/min.

When the deagglomerator was added to the system just ahead of the cyclone the results shown in table 23 were obtained.

The small cyclone T4 was also tested with four different pollens, rice starch, wheat smut, corn smut and two miscellaneous materials as shown in tables 24-26. In general only an occasional pollen grain was observed in the outlet of the cyclones and this was at the lower air flow rates of 60 ℓ/min and less. Usually the separation was about 99% or better effective where the pollens were 7-8 μm or larger. In most cases the small particles observed were due to dust, debris and smaller fragments rather than actual pollen grains. In the case of the pigweed and mulberry pollens the cyclone could be used as a preparative method for cleaning up the pollen. With the pollens there was no deposition of particles or dust on the inside walls of the cyclone. In the case of the smuts and with SM particles, there usually was some deposition.

The effect of flow rate on the sharpness of separation is shown graphically in figure 29 for the SM and corn smut particles. The data collected for these two cover a flow range of 40 to 80 ℓ/min and suggests 60 ℓ/min as the optimum flow rate for SM particles.

6. Positive Pressure Air Flow System

The air flow system was then revamped to operate under a low positive pressure instead of the previous procedure of slight vacuum. This was done with the use of a diaphragm pump for operation in the air flow range of 50-80 ℓ/min.

At first, the pulsing action of the diaphragm pump prevented the proper functioning of the cyclone. After a pulse dampener was installed this problem was overcome. The first checkout of the system was then performed as shown with the use of a 50/50 mix of corn and wheat smuts (table 27).

The CL apparatus was then modified at the tape impact area. We designed and constructed another holder and adjustable jet for the introduction of the air-borne particles from the outlet of the T4 cyclone onto the moving 16 mm tape. The new jet apparatus for use at a positive pressure of 30-40 mm Hg and flow rates in the 40-80 ℓ/min range is shown in figure 30.

The cyclone and deagglomerator was then tested. A series of runs were made using the SM particles as the test particles, injecting them into the air stream in the filtered air inlet to the diaphragm type pump. Portions of the different tapes obtained were cut out and analyzed for particle size distribution (table 28). Figure 31 shows SEM photomicrographs at 500X and 1000X of a portion from one of these tapes.

III DISCUSSION AND RECOMMENDATIONS

The deagglomerator has been very effective in reducing the size of SM particle agglomerates. On the other hand, there is no evidence that it breaks up individual pollen grains or other single particles.

The cyclone separators are also quite effective in separating fine particles from the air stream after deagglomeration. We feel the objectives of the study have been met. We were asked to determine the kinds of particles causing false alarms with the CL detector and to devise procedures for minimizing such alarms. The best and perhaps the only parameter on which to base separation of the target material is particle size. The deagglomerator to reduce the particle size of the target substances and size-selective cyclone to remove larger particles of most interfering substances is a practical solution to the overall problem.

The T4 cyclone was found to have optimum performance at flow rates of 50-60 ℓ/min. The experiments conducted so far indicate it to be very effective in eliminating the larger particles >5 μm and thus a very useful addition or modification to the CL apparatus. Both T-1B and T4 cyclones are suitable for particle cut-off in the 4-5 μm range. The T-1B is more useful for tape impaction at low flow rates of 2-5 ℓ/min following the aerosol concentrator, whereas the T4 cyclone is useful in the 50-60 ℓ/min flow range but has not yet been tested in conjuction with the aerosol concentrator. It may be useful alone, although it handles much smaller volume of air than the aerosol concentrator, but there will be no loss of the small particles.

We feel we have shown the individual components of this system do work. It would be worthwhile to optimize the sizes of each component as part of a compatible total CL unit. Each component has its own optimum flow rate for best performance. This would have to be considered in assembling a final unit with adequate overall flow rate and high efficiency for testing particles in the 3-5 μm range.

Respectfully submitted,

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APPENDIX A
TABLES

Table 1. Substances Tested for Chemiluminescence Response

Group	Category	Number tested	Positive response	% Positive response
A	Biologicals	38	34	90
B	Natural fibers and hairs	28	18	64
C	Man-made fibers and hairs	19	6	32
D	Rocks and minerals	97	4	4
E	Abrasives and catalysts and cements	45	1	2
F	Cleansers and detergents	14	2	14
G	Fertilizers	20	8	40
H	Food products	60	44	73
I	Metals	90	2	2
J	Polymers	15	0	0
K	Industrial dusts	66	8	12
L	Combustion products	29	4	14
M	Miscellaneous	31	4	13
		552	135	25
α	A, B, C, G, H	165	110	67
β	D, E, F, I, J, K, L, M	387	25	6

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Table 2. Particulate Substances Giving a CL Response >10 mV

Algae	Disodium phosphate	Kelp
Dandruff	Sheep manure	Lemon powder
Foramanifera	Milorganite	Linseed meal
Insect parts	Superphosphate	Malt grain
Pollens	5-10-30 fertilizer	Maltose
Spores	12-12-12 fertilizer	Monocalcium phosphate
Fungi	Alfalfa	Mustard
Animal hairs	Bean meal	Peanut hulls
Natural fibers	Bone meal	Pepper
cotton	Brewer's grits	Pudding mix
flax		
jute	Caffeine	Rice hulls
straw	Castor pomace	Seed cleaning dust
wood		
Man-made fibers	Citric acid	Sodium carbonate
acetate	Citrus dust	Sorghum mill feed
calcium algenate		
carbon	Cocoa chaff	Soybean meal
Acoustic tile	Ground corn	Starch (wheat)
Attapulgite	Cottonseed meal	Soybean meal
Bentonite	Dog food	Sucrose
Glauconite	Feather tankage	Tea
Ilmenite	Fish meal	Walnut shells
Trisodium phosphate	Flaxseed meal	Bi-Cd alloy spray
Diammonium phosphate	Gelatin	Carbon black
Armorganic tankage	Ginger	Copper sulfate
Coke (breeze to stack)	Paper mill effluent	Incinerator flyash
Glass balloons	Sodium sulfate	Blood (spray-dried)
Insulator dust	Tile dust	Concrete block
Oxalic acid	Oil soot	Feathers (hydrolyzed)
	Plaster	

Table 3. Effect of Fiber Size on CL Response

Substance	Atlas No	Sample size	Response (mV)
Feather	589	macro	90
Feather	589	5 mm length barb	9
Feather	589	10 mm length barb	24
Feather	589	15 mm length barb	57
Silk	55	macro	370
Silk	55	5 mm length	3
Silk	55	10 mm length	3
Silk	55	15 mm length	23

Table 4. Effect of Sample Size on CL Response

Substance	Sample Size	Response (mV)
Spanish moss	1-0.2 mm flake	20
Silk	1 fiber	8
Silk	Several fibers	41
Lycopodium	<10 particles	1
Lycopodium	~100 particles	17
Dog hair	1 hair	0
Dog hair	3 hair cut/up	30
Armorganic tankage	<10 particles	45
Carbon black	<10 particles	9
Carbon black	~100 particles	90
Oil soot	Very small	59
Oil soot	~10 particles	off-scale
Blood, dried	Small	off-scale*

* The instrument had to be completely and thoroughly cleaned before the base line reading could be brought back to zero.

Table 5. Sizes of Selected Biological Particles

Substance	Diameter (in μm)*
Epithelial cells	5
Insect parts	99% >10
Elm pollen	35
Cottonwood pollen	22
Dandelion pollen	25
Horse-chestnut pollen	20
Lamb's quarters pollen	26
Sugar maple pollen	35
Marihuana pollen	23
Red oak pollen	34
Pigweed pollen	26
Pine pollen	55
Balsam poplar pollen	22
Ragweed pollen	19
Timothy grass pollen	32
Spanish moss	30
Fern spores (cinnamon)	55
Fern spores (marginal shield)	35
Fern spores (rattlesnake)	25
Fungal conidia	10
Aspergillus niger spores	3.6
Penicillium notatum spores	5
Wheat smut spores	4.5
Mold spores	3 - 5
Mushroom spores (Coprinus comatus)	7

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Table 5 (continued)

Substance	Diameter (in μm)*
Mushroom spores (Agaricus campestris)	6
Mushroom spores (puffball)	3.5
Moss spores	12
Lycopodium spores	35
Trichomes (Silver maple)**	20
Starch, arrowroot	35
Starch, corn	10
Starch, potato	25
Starch, rice	6
Starch, wheat	3 - 25

* Estimated aerodynamic diameter

** Almost all other trichomes and seed hairs are >20 μm

Table 6. Approximate Sensitivity of CL Detection with Lamb's Quarter Pollen and Plant Fragments

Particle diameter (in μm)		Number of particles for positive response
pollen grains	30	1
	20	2
Associated plant particles	10	8
	5	30
	3	100
	2	200
	1	600

Table 7. CL Detection of Inorganic Acids and Ammonia

Compound	Reading (mV)
NH_4OH	90, 90
HCl	0
HNO_3	0
H_2SO_4	4, 90

Table 8. Effect of Washing of Particles on CL Response

Substance	Response (mV)		Comments
	Unwashed	Washed	
Acetate rayon	20	0	inactive
Acoustic tile	2	0	inactive
Alfalfa	90	77	active
Algae	10	21	active*
Antigorite	40	1.5	inactive
Aspergillis spores	49	4	active*
Bone	90	52	active
Cat hair	16	1	inactive
Cottonwood pollen	90	23	active
Dandruff	4	2	active
Dog food	90	24	active
Glass spheres	20	0	inactive
Insect parts	off-scale	74	active
Lamb's quarters pollen	23	20	active
Paper	66	34	active
Poultry feathers	90	10	active*
Poultry feathers	7	3	active*
Red oak pollen	68	47	active
Silk	3.5	3	active
Spanish moss	off-scale	54	active
Stellate hairs	32	5	active
Sugar maple pollen	51	23	active
Tea	19	10	active
Wheat smut spores	19	10	active
Wood pulp	4	4	active

* Sample size effect

Table 9. Effect of Washing Particles on CL Detector Response

Material	Previous Data		New Data	
	Unwashed	Washed	Unwashed	Washed
Alfalfa	off-scale	77	off-scale	5
Alfalfa	48	42	48	0
Aspergillus	49	4	off-scale	9
Aspergillus			42	5
Armorganic tankage	71	48	off-scale	50

Table 10. Infrared Analysis of Particle Extracts

Extract	Major functional groups
Water extract of Maryland grass	COOH, CH_3, CH_2, COO^-
Ethanol extract of lycopodium	COOH, COOR, CH_3, CH_2
Water extract of dandelion pollen	COOH, CH_3, CH_2, COH?
Ethanol extract of dandelion pollen	COOR, CH_3, CH_2, COOH?
Unwashed cottonwood pollen	COOH, CH_3, CH_2
Washed cottonwood pollen	COOH, CH_3, CH_2
Ethanol extract of pigweed pollen	COOR, CH_3, CH_2, COH, COOH?
Water extract of dried insects	COOH, COH
Ethanol extract of algae	COOR, COH, CH_3, CH_2, COOH?

Table 11. CL Detector Response for Outside Air Collections

Collection time (sec)	Run 1	Run 2
	CL Response (mV)	CL Response (mV)
5	13	0
10	—	2
30	5	5
60	51	0
180	off-scale	11

Table 12

Particles found on tapes	July 12 plants	July 12 floor	Container debris	C-1	C-2	SM-1	G-1	G-3	S-1	S-2
FIBERS:										
animal hair			+							
cotton, mercerized: colorless			+	+	+		+	+	+	+
black			+							+
blue			+					+	+	
red								+		
feather								+		
glass fiber			+			+		+	+	
orlon, delustered and dyed			+				+			+
paper: nonconiferous chemical wood			+	+	+	+	+	+	+	+
coniferous mechanical wood									+	
rayon: acetate									+	+
viscose				+						
silk, dyed								+	+	
synthetic, unknown				+						
PARTICLES:										
adhesive (chips)	+		+	+	+			+		+
calcite or dolomite	+	+	+	+		+	+	+	+	+
coal			+			+				
epithelial cells	+	+	+	+		+			+	+
flyash	+	+		+		+				
fungus	+	+	+	+		+	+	+	+	
glass particles			+				+		+	+
hematite	+		+	+		+			+	+
metal, white	!					+			?	
paint spray or chips	+		+			+	+	+	+	
paper coating			+			+				+
pollen									+	
quartz		+	+	+		+			+	+
resin, orange-brown							+			
silica cells	+							+		
soot		+								
starch: corn			+	+		+	+	+		+
other (rice or wheat)			+				+			
trichomes							+	+	+	+

(other particles present)

(many other particles present)

List of samples:

July 12 plants = Edgewood plants shaken before Partichrome detector, received July 12, 1972.
July 12 floor = Edgewood floor sweepings, received July 12, 1972.
Container debris = dust from container in which seven samples received August 1 were shipped.
C-1 = Control tape with air sampler on filtered air.
C-2 = Control tape, adhesive only.
SM-1 = SM aerosol.
G-1 = 15 minutes grass.
G-3 = 20 minutes grass.
S-1 = 15 minutes soil.
S-2 = 15 minutes soil.

Table 13. Particle Counts on Alarm and Control Tapes

Tape	Counts/mm^2	Remarks
DPG-1A	?	v. heavily loaded but v. discontinuous adhesive layer
DPG-1C	43	90% biol.; 10% flyash
DPG-3A	735	75% biol.; 25% flyash
6-13-73, Control	22	80% biol.; 20% flyash
6-14-73, Control	trace	100% pollen
DPG-6A	65	large pollen grains
DPG-6B	12 +	1 large debris covered fiber
DPG-6, Control	2	nearly all pollen
DPG-8A	0	— — — —
DPG-8B	>1000	60% pollen, 40% flyash but discontinuous
DPG-9A	108	75% biol.; 25% flyash
DPG-9B	45	90% pollens; 10% flyash
DPG-10A	22	large pollens
DPG-10B	34	large pollens
DPG-10C	865	a single patch of loaded adhesive 0.1 mm^2 in area
DPG-10, Control	2	pollens
DPG-10, Control	11	90% biol.; 10% flyash

Table 14. Effect of Deagglomerator on Maximum Particle Size of Limestone Aggregates

Gap (cm)	Flowrate (ℓ/min)	Max. particle size (μm)
~0.05	5.0	20
~0.05	9.0	20
0.1	5.0	30
0.1	11.0	20
0.5	5.0	50
0.5	12.5	35
1.0	2.5	80
1.0	7.5	70
1.0	12.5	55

Table 15. Effect of Deagglomerator on SM Particle Size

Deagglomerator	Size class (μm)			
	1-3	3-5	5-8	8+
yes	55	34	10	1
no	43	36	15	6

Table 16. Size Selector ("Mark I") Operating at a High Flowrate (160 ℓ/min.; 14 ℓ/min. at Sample outlet C, Fig. 7)

Run	Slot spacing (μm)	Size class (μm)	
		1-5	5+
A	2.5	90	10
B	4.0	86	14
C	5.5	92	8
D	7.0	93	7
E	8.5	93	7
F	10.0	91	9
G	13.0	86	14
H	18.0	87	13

Table 17. Effect of Slot Separation on % Distribution of SM Particles for "Mark II" Size Selector at 100 ℓ/min Flowrate

Slot separation (mm)	Size class (μm) 1-5	5+
3.5	90	10
5.0	91	9
6.5	82	18
8.0	78	22
10.0	76	24
12.0	79	21
14.0	80	20
SM (as received)	96	4

Table 18. Maximum Particle Size Passed vs. Flowrate for Rotameter Settings on Air Flow to Cyclone (T-1B)

Rotameter Setting	Flow ft^3/min	Rate l/min	Particle Size, *μm	Particle Size, ‡ μm
2	0.001	0.03	11.5	15.4
3	0.018	0.51	9.0	12.0
4	0.035	0.99	7.0	9.4
5	0.052	1.47	5.6	7.5
6	0.068	1.92	4.2	5.6
7	0.085	2.40	3.3	4.4
8	0.102	2.87	2.6	3.5
9	0.118	3.34	2.1	2.8
10	0.136	3.85	1.8	2.4
11	0.153	4.33	1.6	2.1
12	0.170	4.81	1.5	2.0
13	0.187	5.29	1.4	1.9
14	0.204	5.77	1.3	1.7
15	0.221	6.25	---	---
16	0.238	6.75	---	---
17	0.254	7.19	1.2	1.6

*Calcite particles, dens. $=2.75\,g/cm^3$

‡Calculated particle size of bacterium (assuming dens. $=1.15$) corresponding to the equivalent calcite particle

Table 19. Size Distribution of SM Particles Before and After Particle Concentrator and Deagglomerator*

Size class μm	SM		
	As received	through concentrator (c)	through c and deagglomerator
0-1	93	21	45
1-2	103	28	40
2-3	31	24	27
3-4	18	18	18
4-5	12	13	11
5-6	7	8	6
6-7	3	5	3
7-8	<1	4	2
8-9	<1	3	1
9+	<1	3	<1

*All data have been normalized to a value of 18 at 3.5 μm

Table 20. Efficiency of Aerosol Particle Concentrator for SM Particles as a Function of Particle Size

Size class μm	Collection efficiency	Number %	Number %		Surface %	Surface %		Weight %	Weight %	
			caught	lost		caught	lost		caught	lost
0-1	4	35	1.4	33.6	2	0.08	1.9	0	0	0
1-2	7.1	38	2.7	35.3	16	1.1	14.9	2	0.1	1.9
2-3	34	12	4.1	7.9	18	6.1	11.9	6	2.0	4.0
3-5	60	12	7.2	4.8	38	22.8	15.2	36	21.6	14.4
5-8	95	4	3.8	0.2	26	24.7	1.3	56	53.2	2.8
		100	19.2	81.8	100	54.8	45.2	100	76.9	23.1

Table 21. Particle Size Distribution of SM Particles

Flow rate (l/min)	% Particles/size class (μm) 1-3	3-4	4-5	5+	Comments
100	73	15	7	5	no particles in cyclone box
150	64	21	7	8	
230	66	23	7	5	
350	79	16	4	1	
~450	80	13	5	2	very few particles collected
—	81	11	4	4	dry SM powder

Table 22. Performance of T4 Cyclone With SM Powder Particle Size Distribution

Air flow rate (ℓ/min)	% Particles/size class (μm) 1-3	3-4	4-5	5+	Comments
45	71	16	6	7	before final polishing
45	74	17	5	4	after final polishing
60	78	14	4.5	3.5	
80	80	12	4.5	3.5	
100	82	11	4	3	very difficult to collect any particles on sampler
—	81	11	4	4	dry SM powder

Table 23. Testing the T4 Cyclone With SM Particle Size Distribution*

Air flow rate (ℓ/min)	% Particles/size class (μm) 1-3	3-4	4-5	5+	
60	79	13	5	3	cyclone stream
60	80	12	5	3	
60	80	10	6	4	cyclone box
—	81	11	4	4	dry SM as received

* using deagglomerator

Table 24. Performance of T4 Cyclone with Some Pollens and Starch (Particle Size Distribution)

Air Flow (ℓ/min)	Conditions	% particles/size class (μm) 1-3	3-4	4-5	5-10	10+	
Dandelion Pollen							
60	w/o* cyclone + DA**	48	14	11	24	3	a
60	with cyclone + DA**	50	18	11	18	3	a
60	with cyclone + DA**	76	13	5	6		a
			40		60		b
Pigweed Pollen							
70	w/o* cyclone + DA**	51	7	3	12	27	
70	with cyclone + DA**	80	8		7	5	
		—	—		—	100>8 μm	c
Giant Ragwood Pollen							
60	w/o* cyclone + DA**	50	13	6	17	14	
60	with cyclone + DA**	42	13	12	28	5	c
			26		74		
Mulberry Pollen							
40	w/o* cyclone + DA**	58	11		7	24	
40	with cyclone + DA**	60	24		11	5	
50	with cyclone + DA**	82	10		5	3	
60	with cyclone + DA**	75	16		6	3	
		—	—		—	100	c
Rice Starch							
90	w/o* cyclone or DA**	41	35	35	21	3	
90	with DA** only	41	28	28	28	4	
90	with cyclone alone	81	15	15	4	—	
90	with cyclone + DA**	78	19	19	4	—	

* w/o = without

** DA = deagglomerator

a= Fragments and debris associated with pollen, plus an occasional pollen grain

b= Cyclone box after runs

c= Cyclone box

Table 25. Performance of T4 Cyclone with Smuts
(Particle Size Distribution)

Air Flow (ℓ/min)	Conditions	% particles/size class (μm) 1-3	3-4	4-5	5-8	8+	
Wheat Smut							
70	w/o* cyclone or DA**	40	11	18	27	4	
70	with cyclone + DA**	66	12	8	12	2	
90	with cyclone + DA**	54	25	10	10	1	d
		55	26	9	9	1	d
Corn Smut							
60	w/o* cyclone, with DA**	35	4	3	7	51	
40	with cyclone + DA**	57	16	12	6	9	e
50	with cyclone + DA**	66	8	5	5	16	
60	with cyclone + DA**	75	9	5	2	9	
		14	4	12	54	16	f
Mix of 50/50 Corn & Wheat Smuts							
40	w/o* cyclone, with DA**	20	6	16	44	15	
40	with cyclone + DA**	47	7	5	31	10	
60	with cyclone + DA**	26	3	4	43	24	
		14	11	24	40	11	c

* w/o = without
** DA = deagglomerator

d = Some smut collects on walls of cyclone box
e = Very little smut in box at this flow rate
f = Some smut collects in cyclone box at 50 & 60 l/min.
c = Cyclone box

Table 26. Performance of T4 Cyclone with Miscellaneous Materials (Particle Size Distribution)

Air Flow (ℓ/min.)	Conditions	% particles/size class (μm) 1-3	3-4	4-5	5-10	10+	
Lake Algae							
60	w/o* cyclone or DA**	76	15	5	4		
60	with cyclone + DA**	72	17	6	5		
		49	10	7	34		d
	dry algae alone (not aerosoled)		80		12	8	
Insect Parts							
60	w/o* cyclone or DA**	72	12	6	8	2	
	with cyclone + DA**	78	10	5	5	2	
			38		11	51	c

* w/o = without
** DA = deagglomerator

d= Sometimes attaches to walls of cyclone box
c= Cyclone box

Table 27. Performance of T4 Cyclone Under Positive Pressure With Smut Mix (Particle Size Distribution)

Air flow (ℓ/min)	Conditions	% Particles/size class (μm) 1-3	3-4	4-5	5-8	8+	Comments
~60	with cyclone + DA	42	15	8	26	9	cyclone stream
		19	22	30	24	4	cyclone box

Table 28. Particle Size Distribution of SM Particles on Tape through Cyclone and Deagglomerator

Run no.	% Particles/size class (μm)				
	1-3	3-4	4-4	5-8	8+
A	69	17	7	6	1
B	78	14	4	4	trace
C	77	15	5	3	0
Average	75	15	5	4	1

APPENDIX B
FIGURES

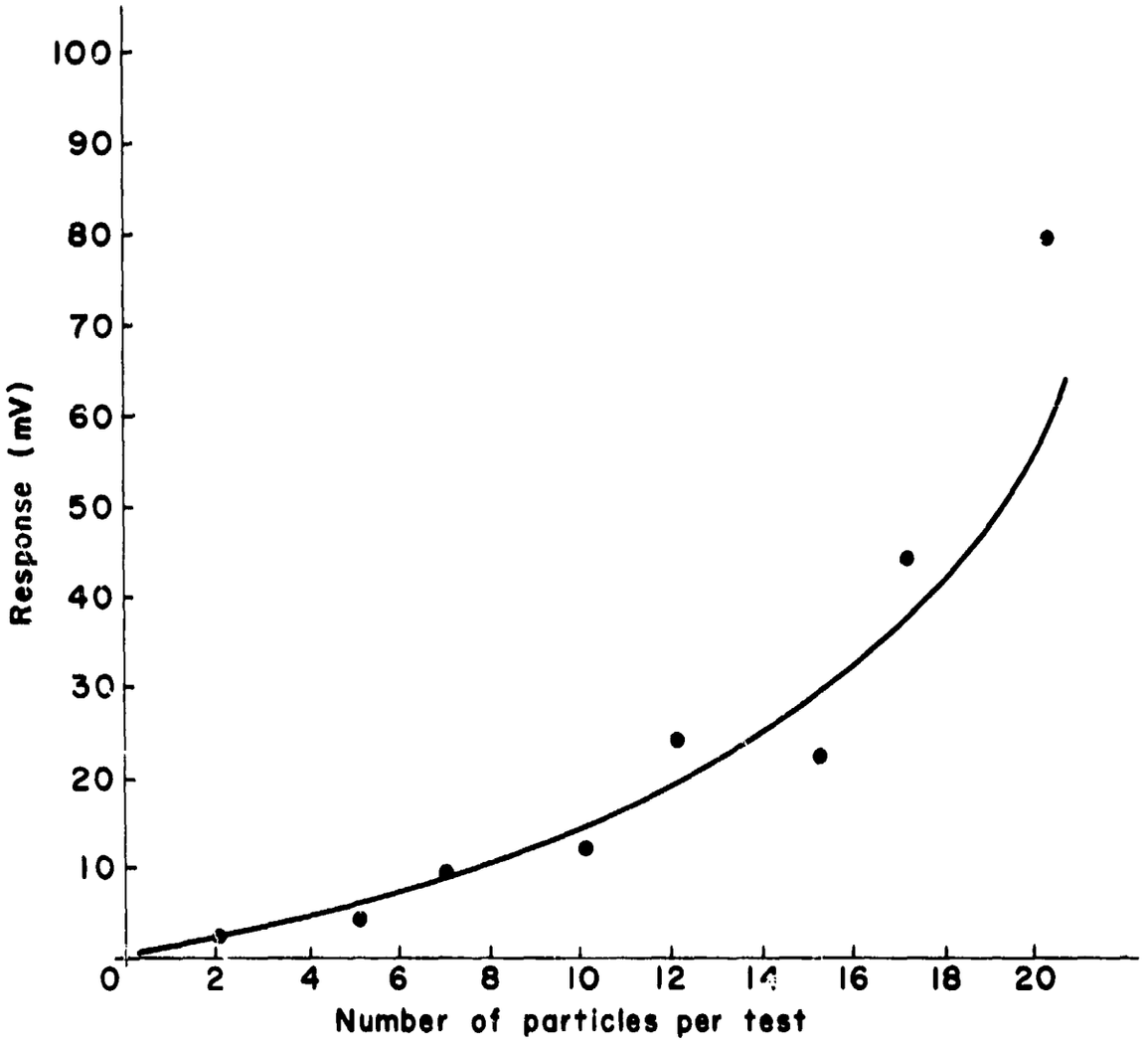


Figure 1. CL response of alfalfa dust as a function of number of particles per test.

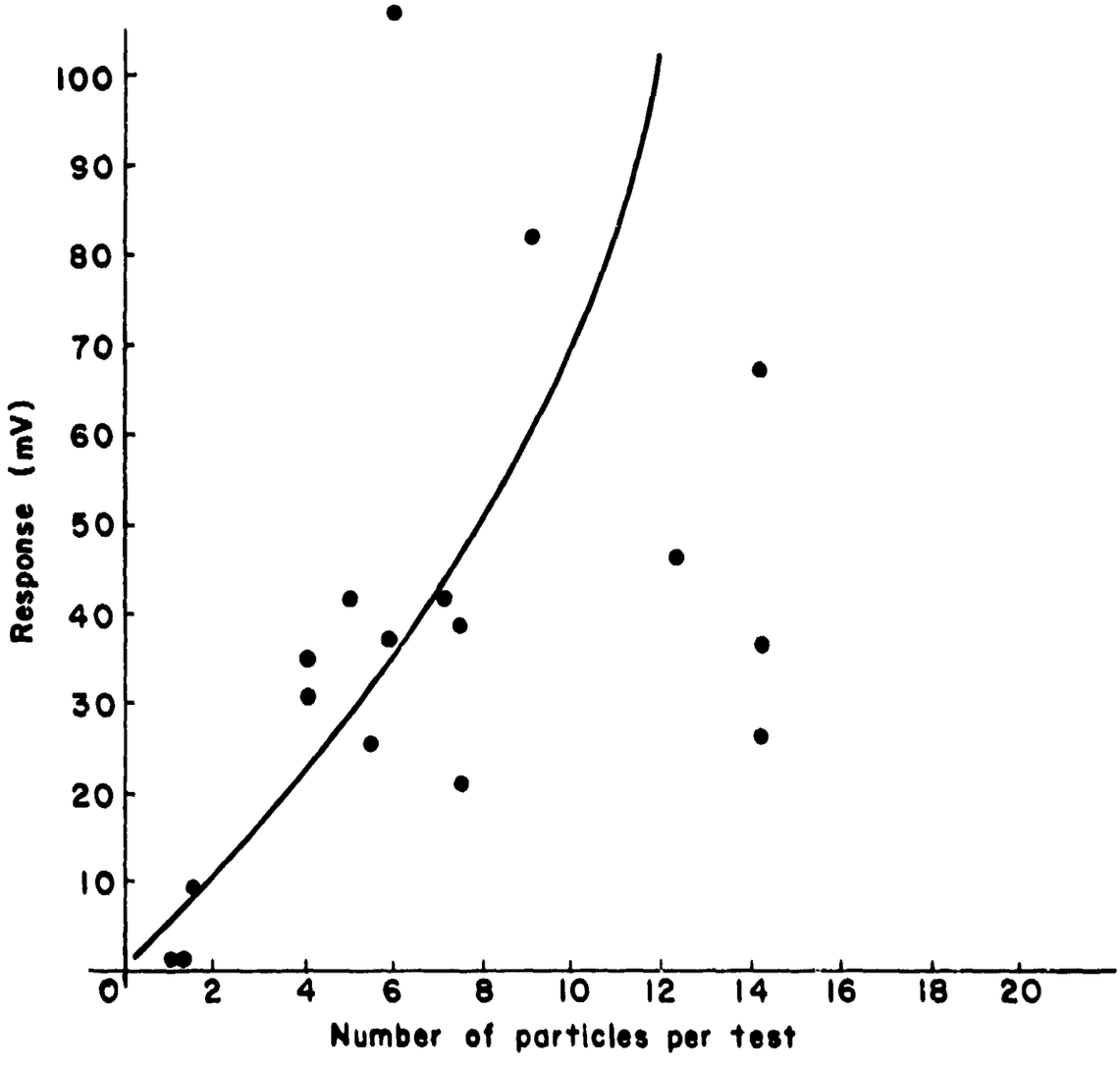


Figure 2. CL response from cottonwood pollen as a function of number of grains per test.

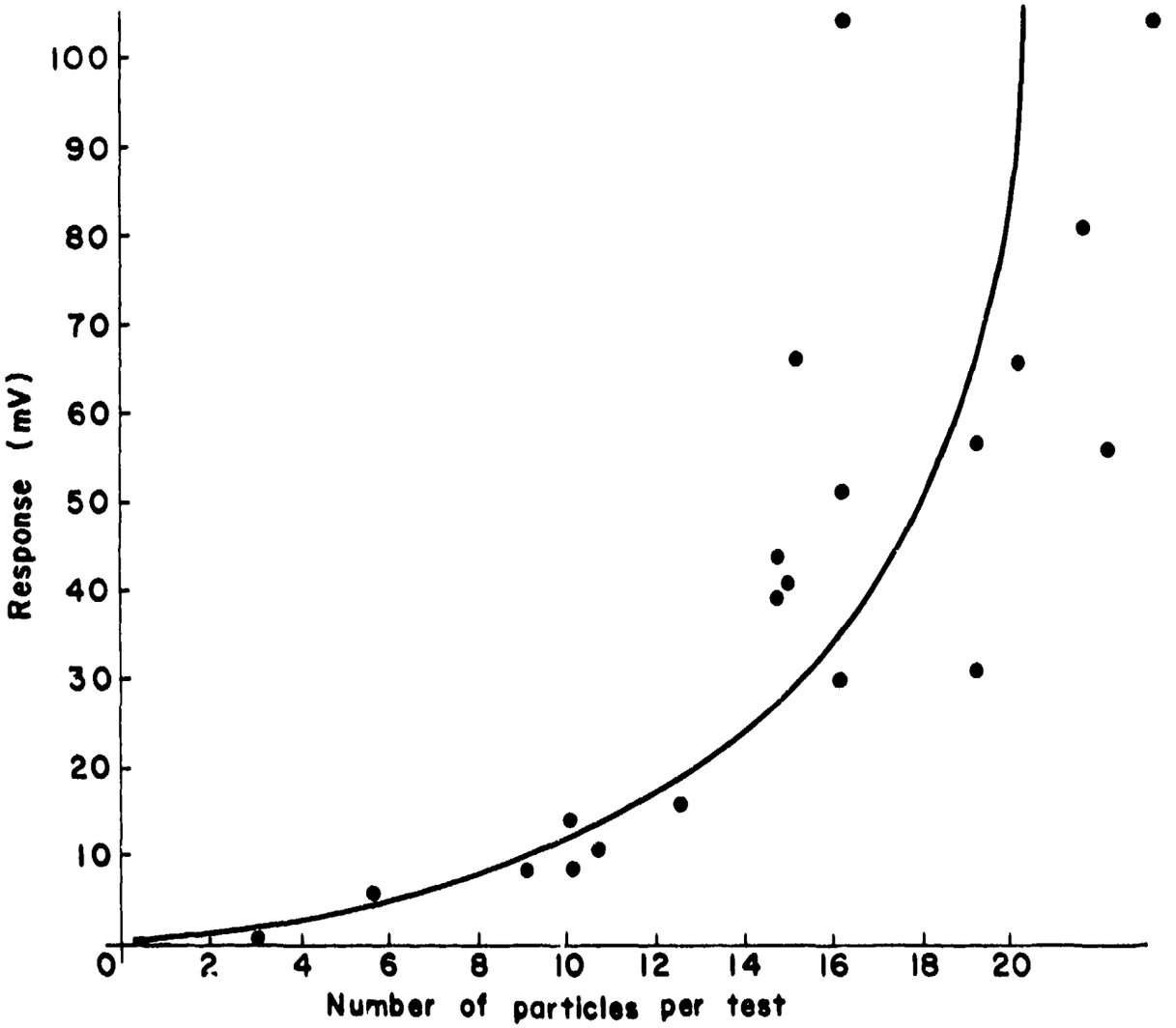


Figure 3. CL response of sugar maple pollen as a function of number of grains per test.

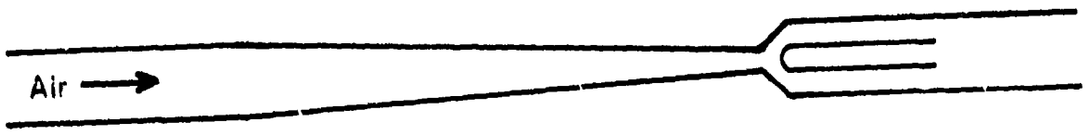
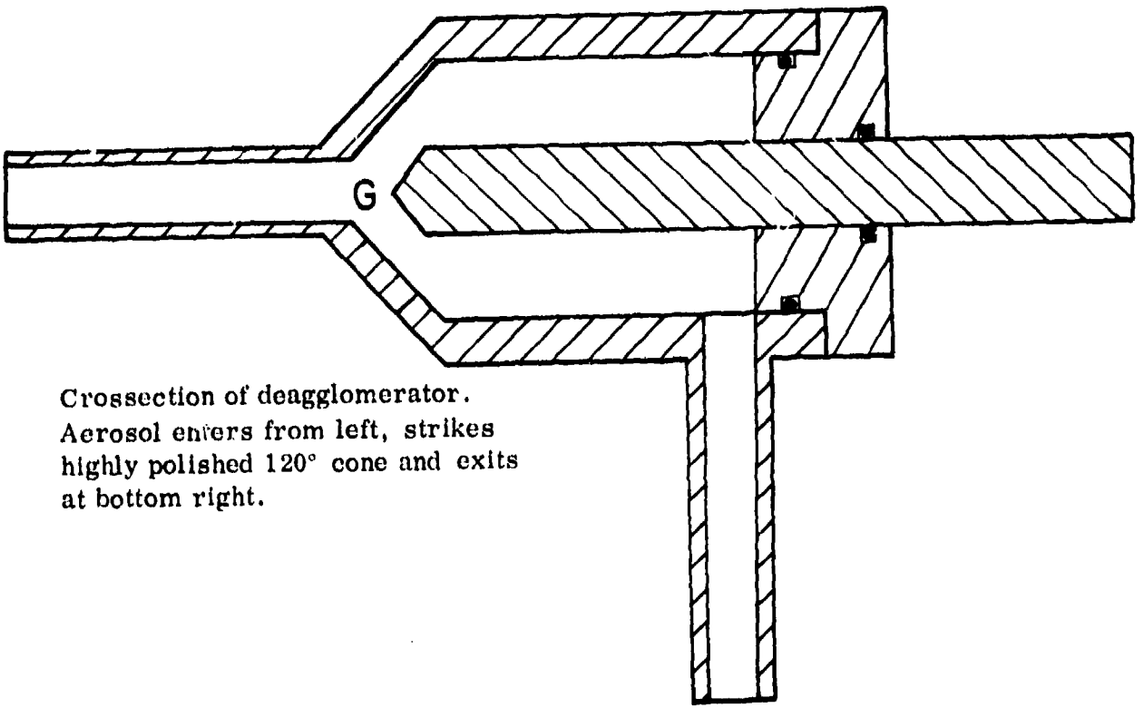


Figure 4. Schematic drawing of a particle-aggregate size reducing system.



Crossection of deagglomerator. Aerosol enters from left, strikes highly polished 120° cone and exits at bottom right.

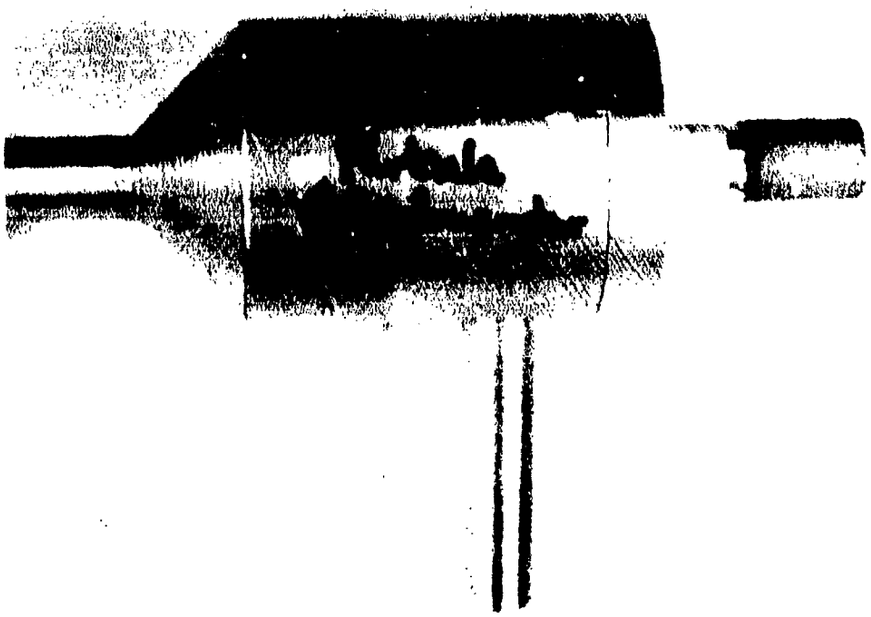


Figure 5. Photograph of deagglomerator (actual size).

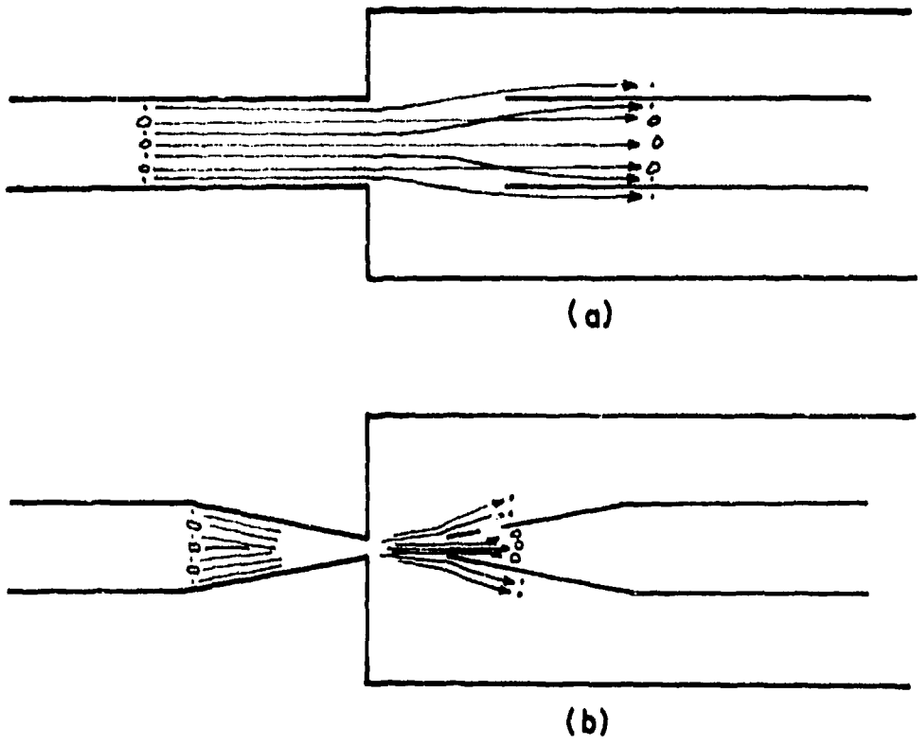


Figure 6. Top and side views of the size selector

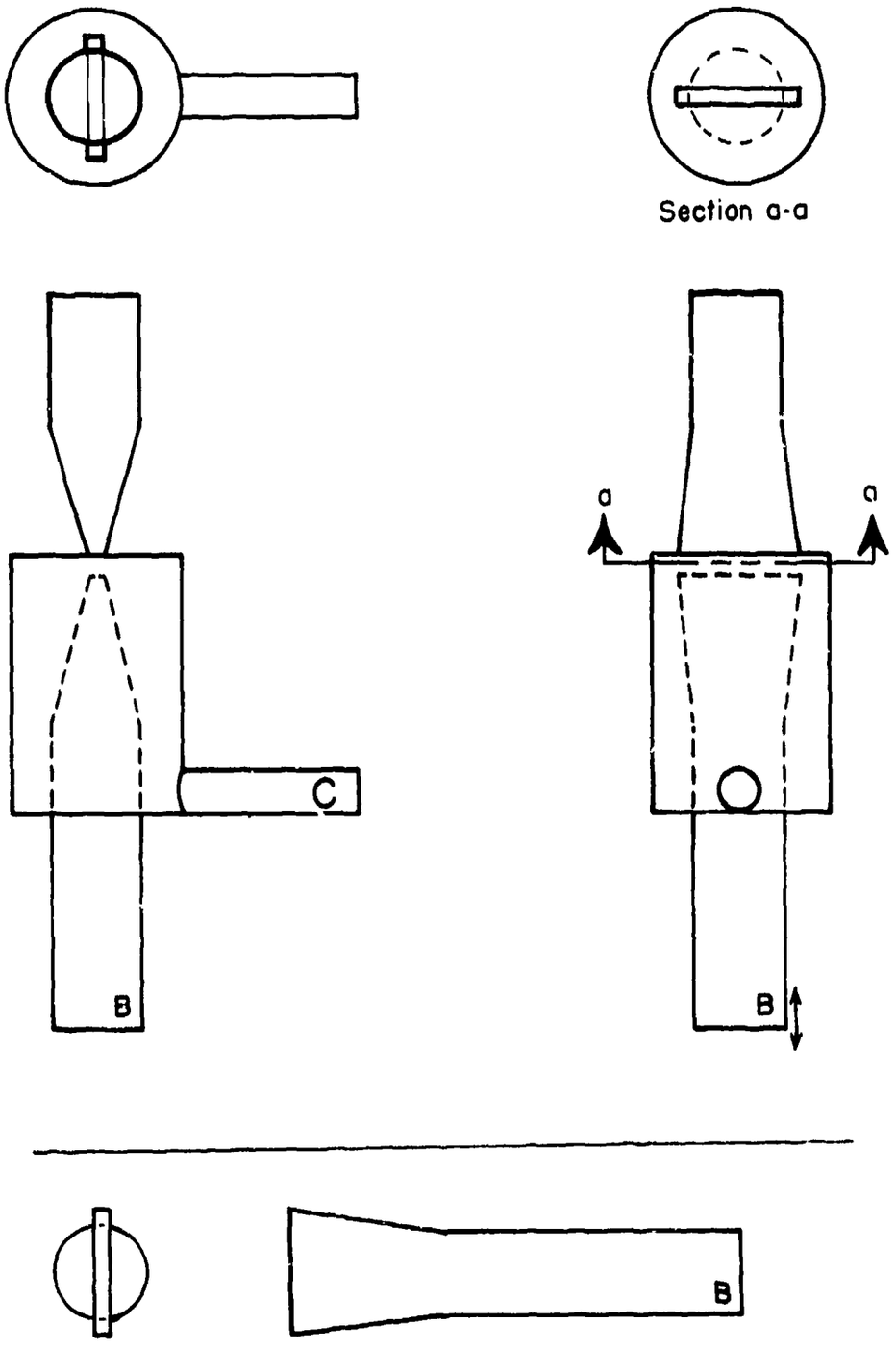


Figure 7. Size selector (Mark I) (concentrator)

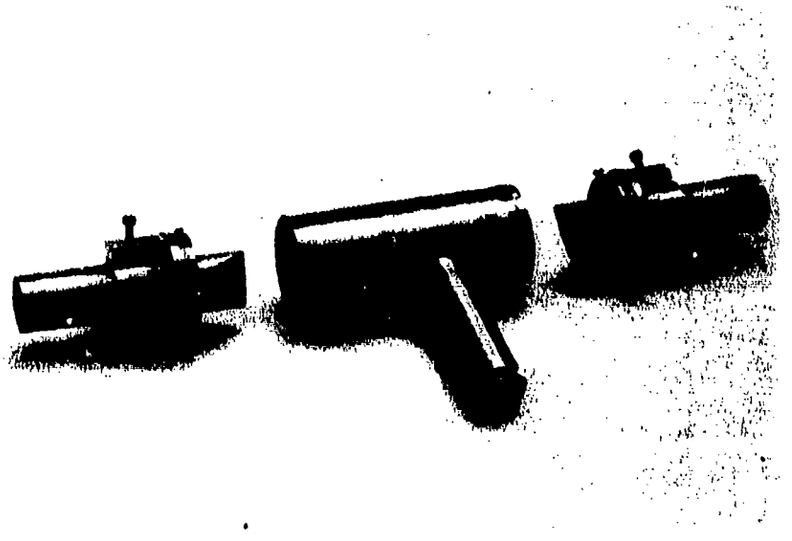


Figure 8. Exploded view of Mark II size selector

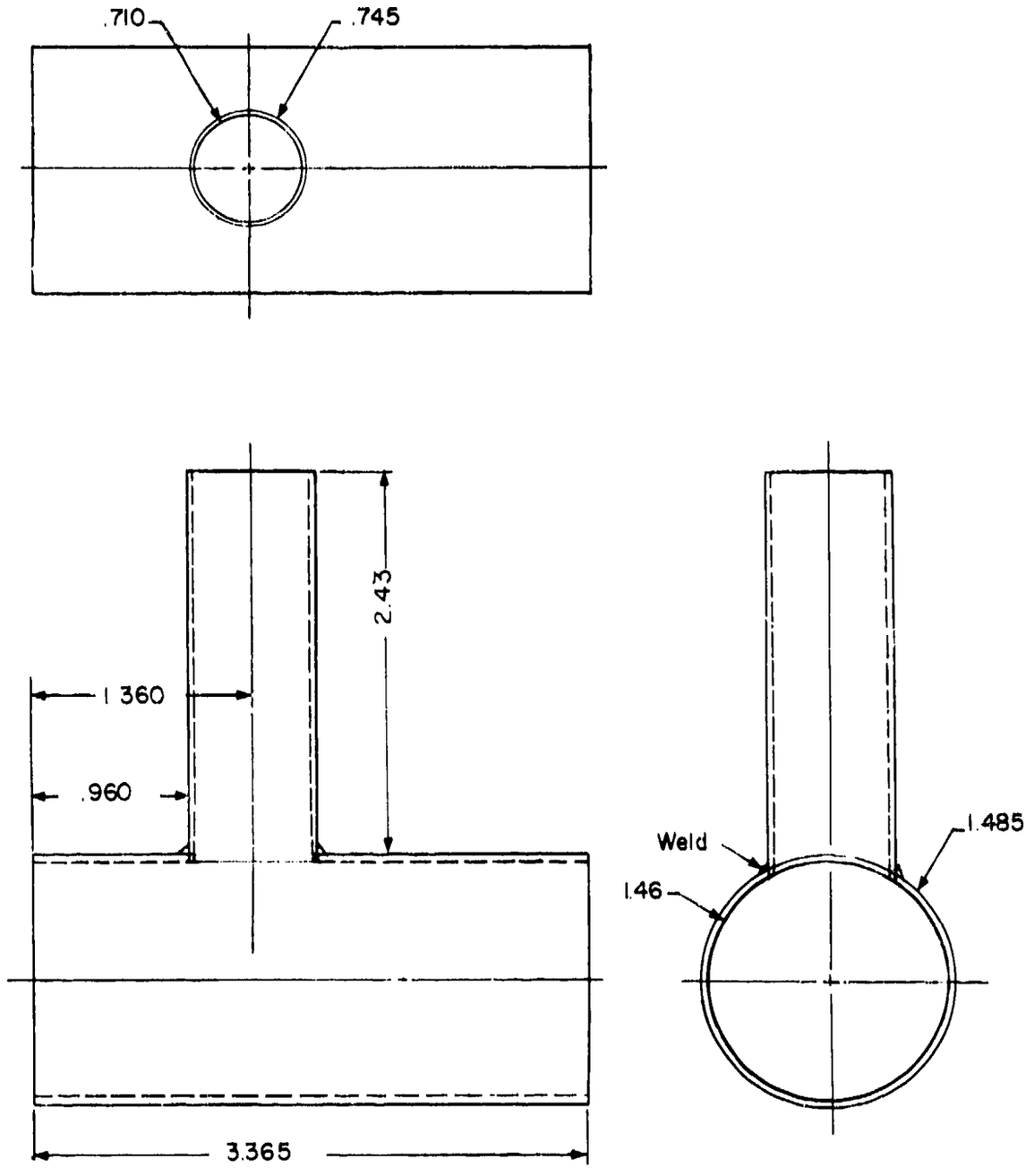


FIGURE 9. Drawings for Mark II size selector

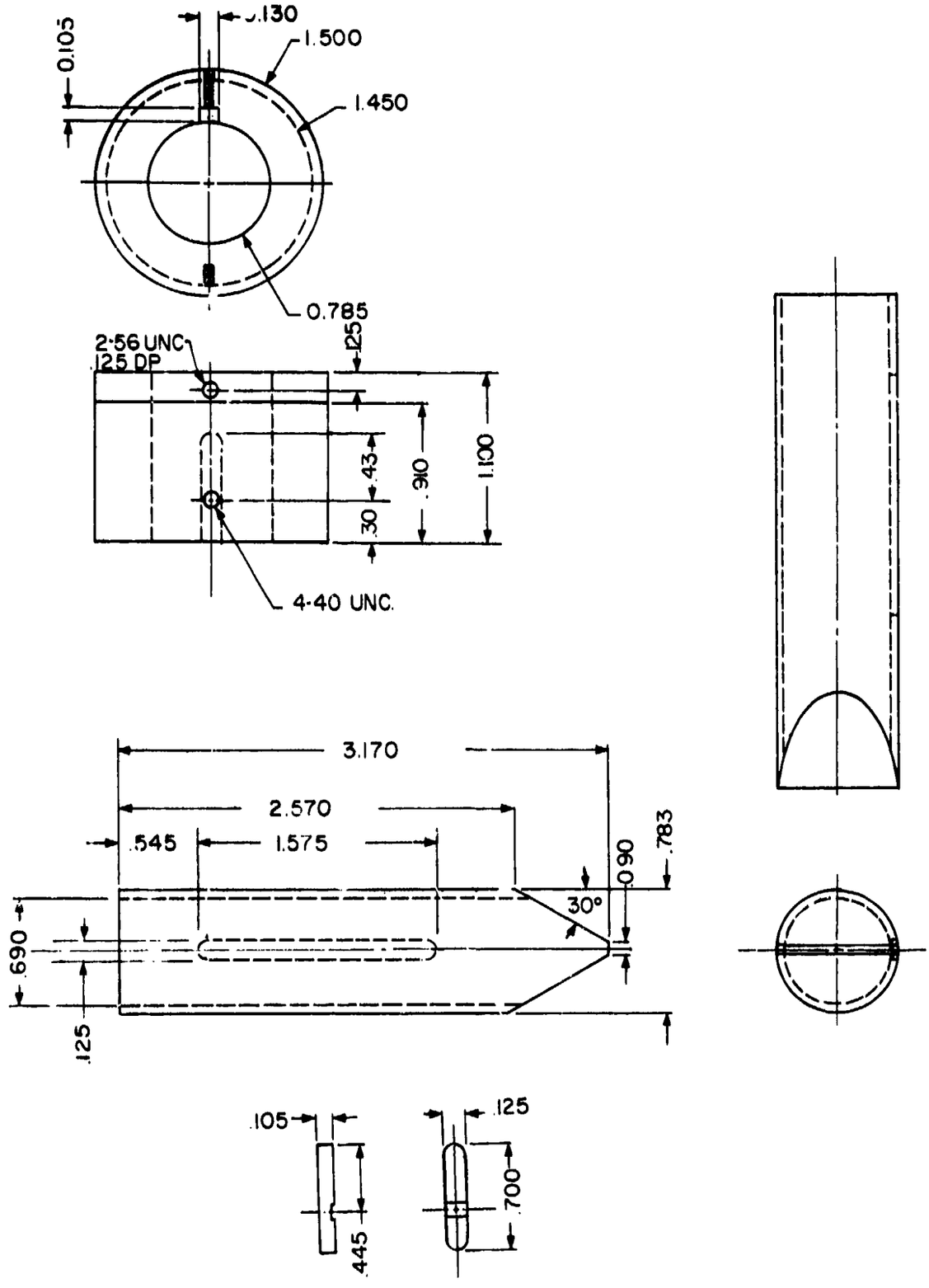


FIGURE 9. (continued) Drawings for Mark II size selector

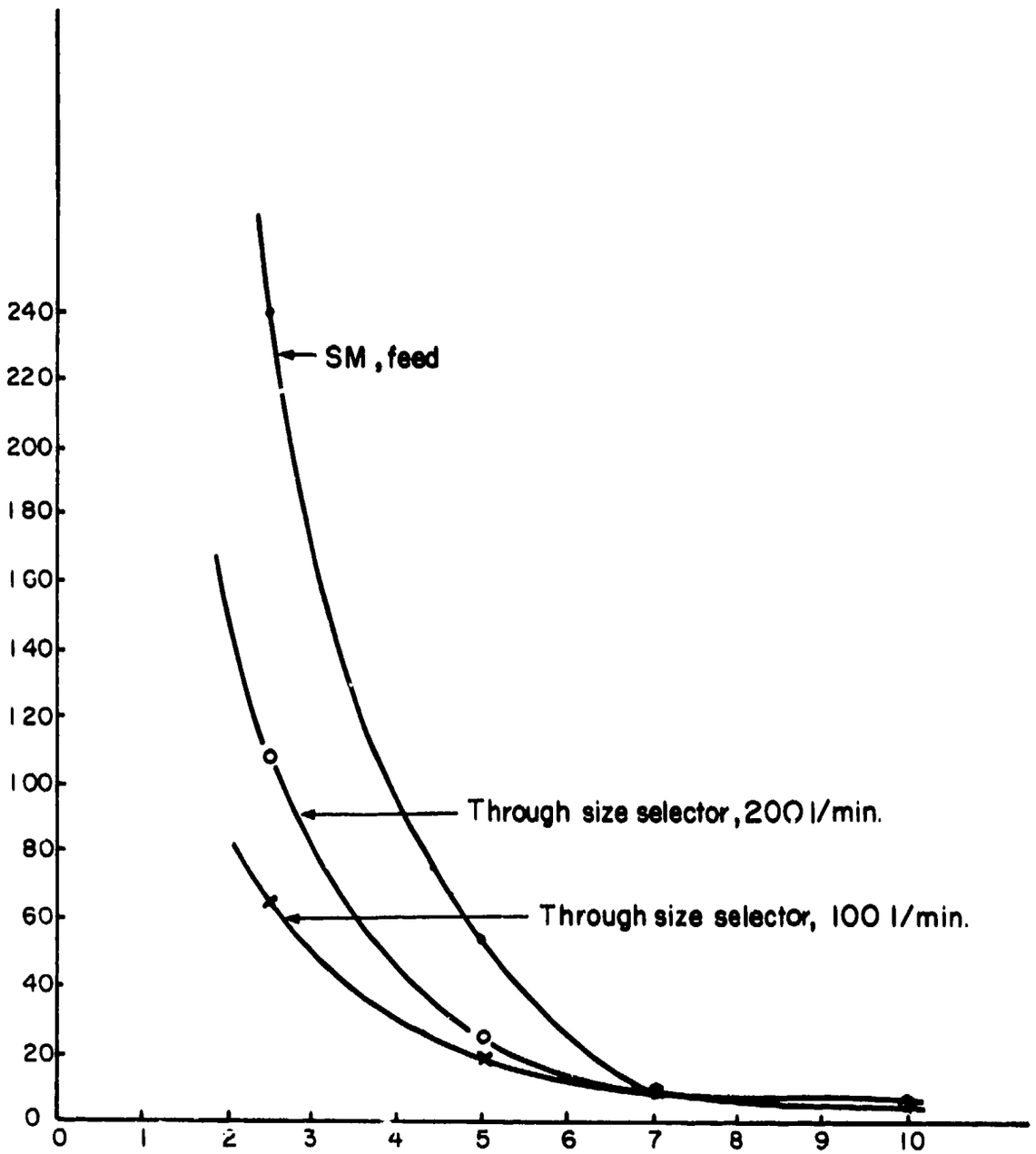
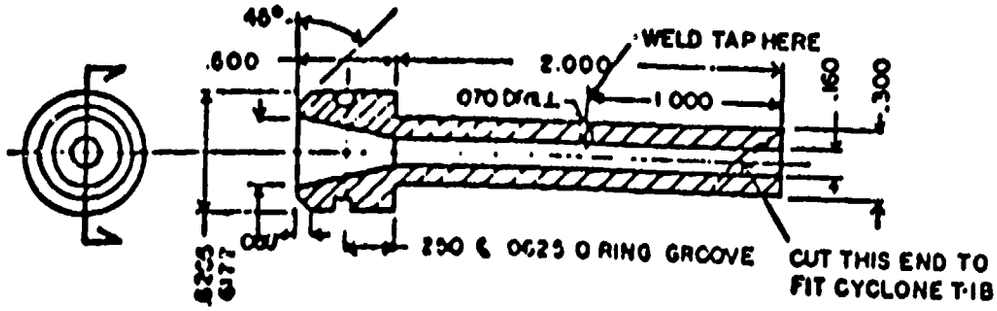
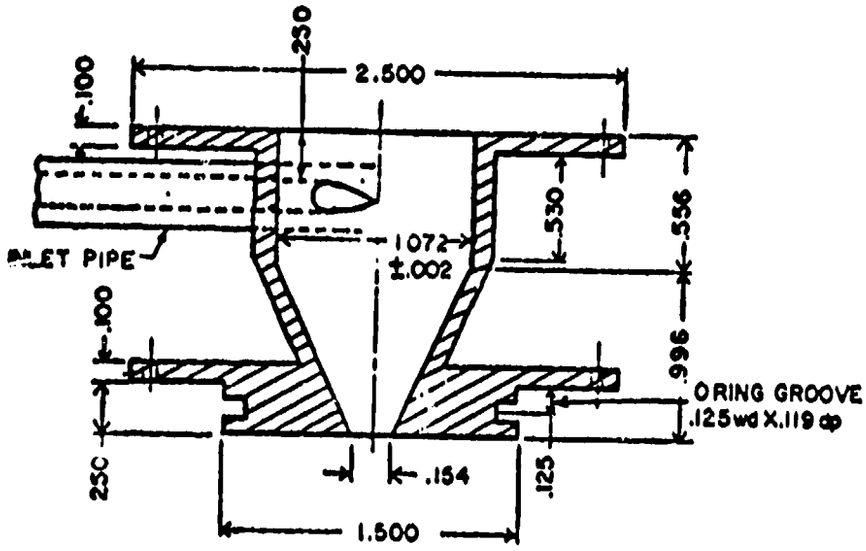


FIGURE 10. Particle size distribution of SM particles through Mark II size selector at 100 ℓ/min. and 10 mm slot separation and 200 ℓ/min. and 15 mm slot separation.



INLET PIPE FOR CYCLONE T-1B



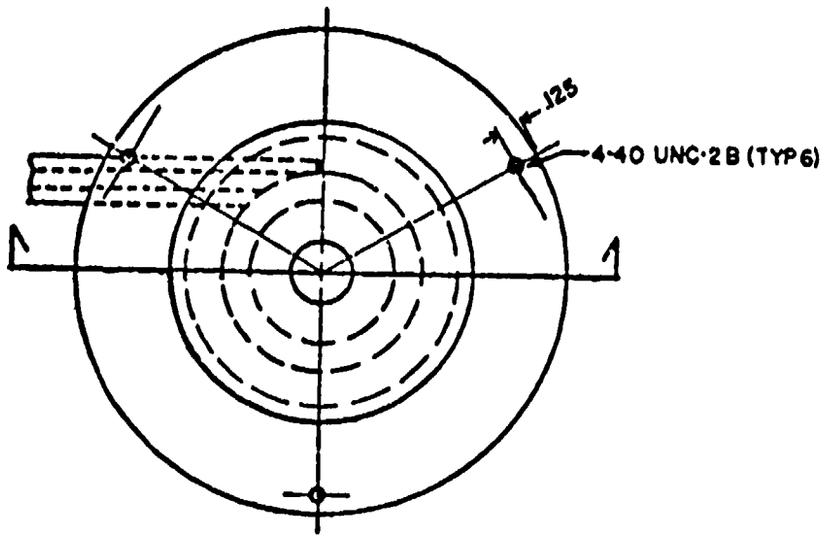


Figure 11. Cyclone T-1B

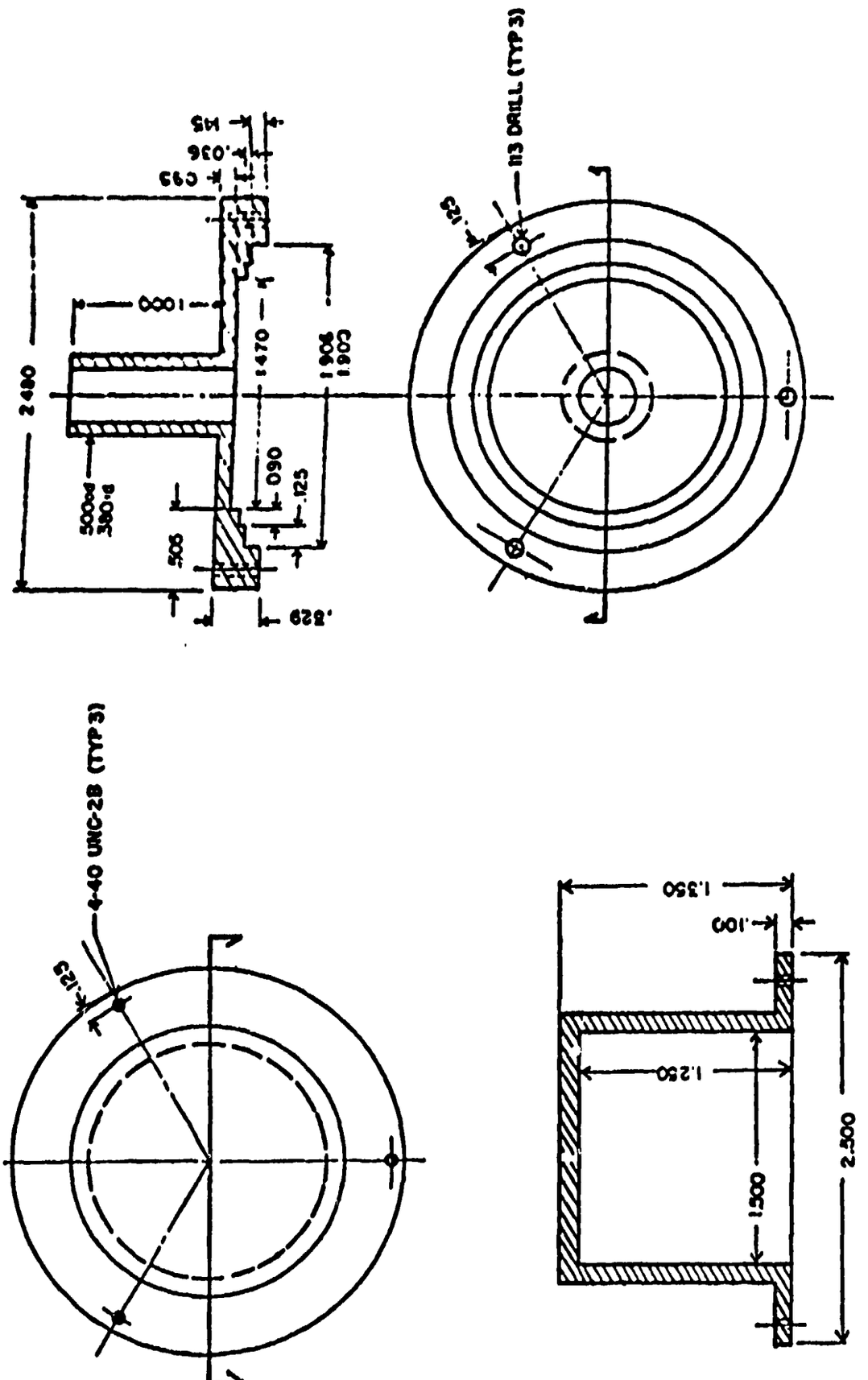


Figure 11. Cyclone T-1B

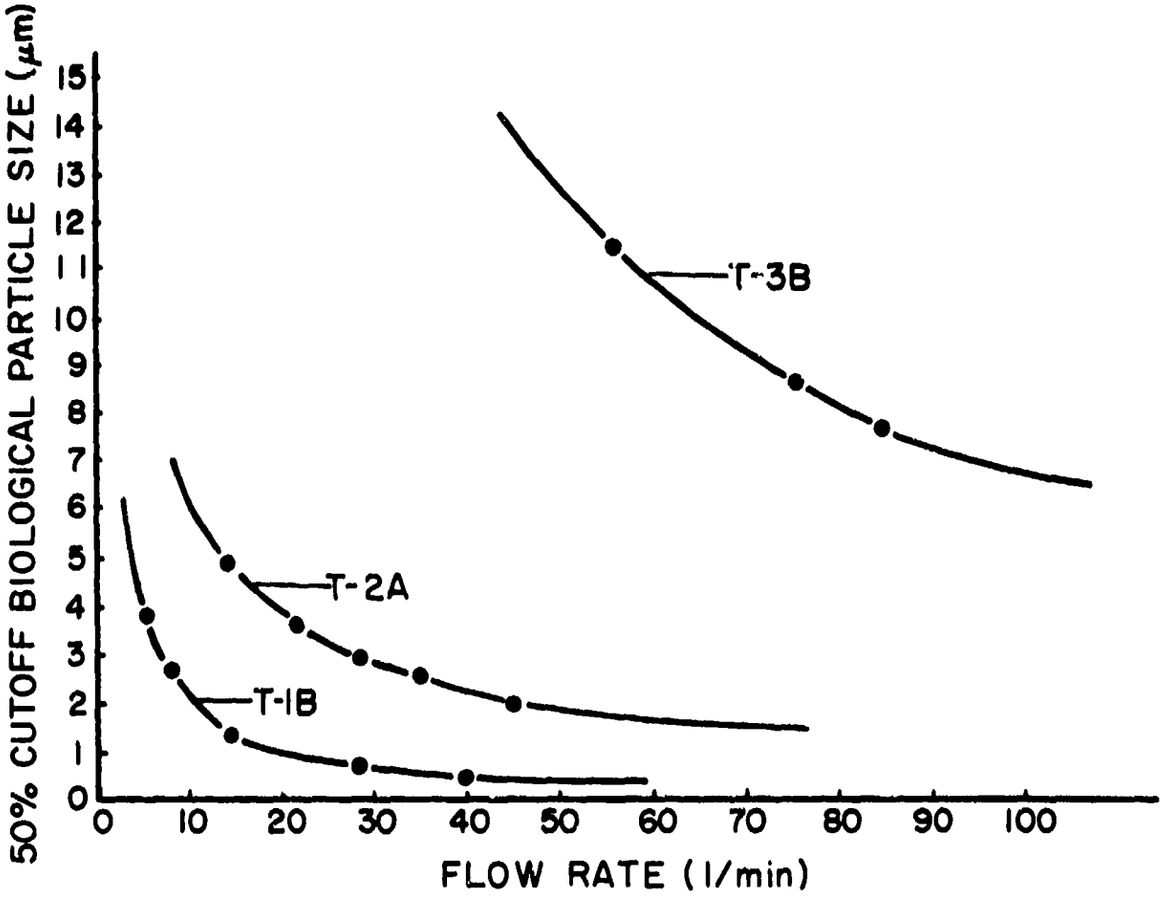


Figure 12. Comparison of three Size Selective Cyclones

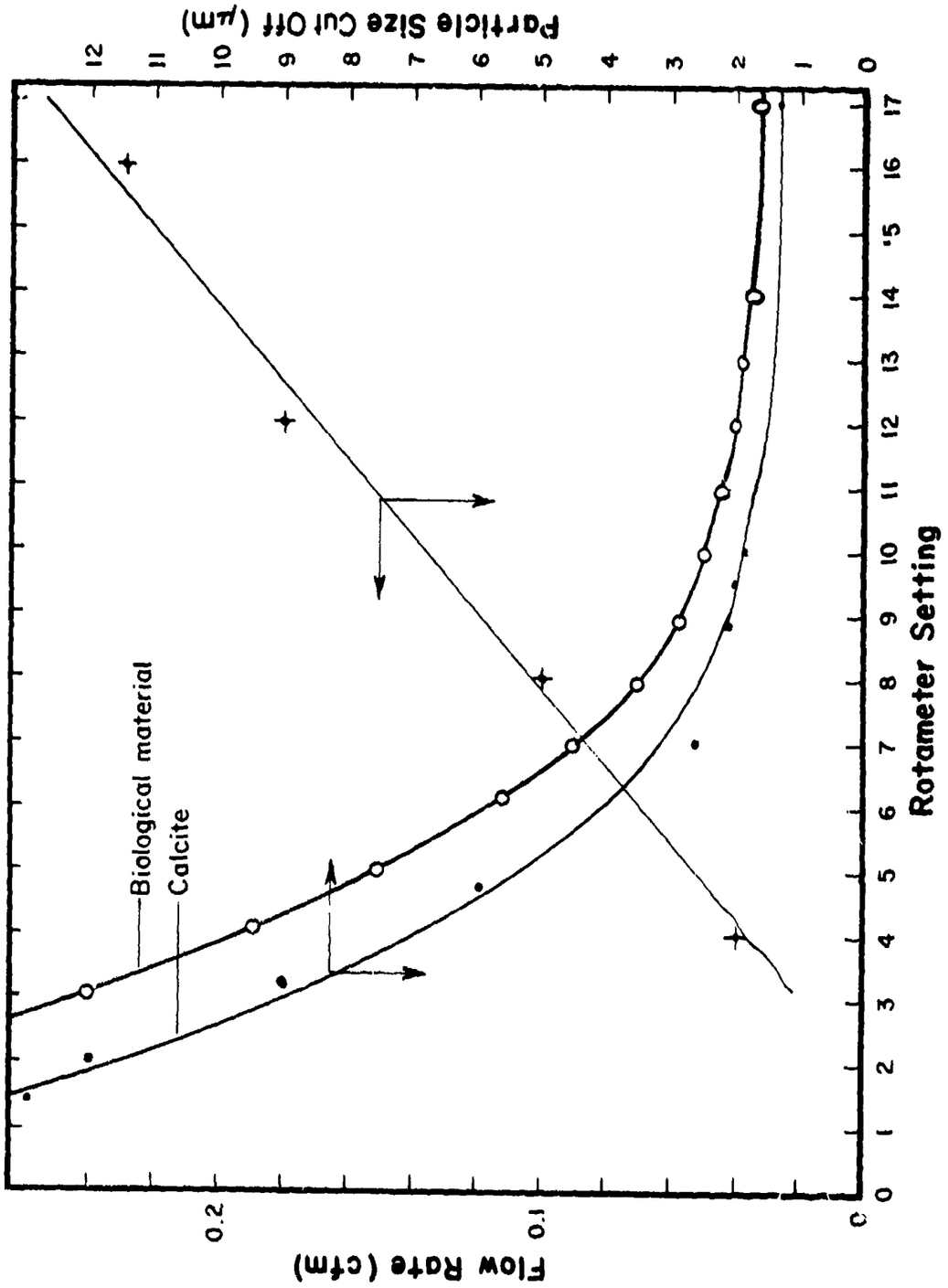

Particle Size Cut Off (μm)
12
11
10
9
8
7
6
5
4
3
2
1
0
Flow Rate (cfm)
0.2
0.1
0
Rotameter Setting
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Biological material
Calcite

Figure 13

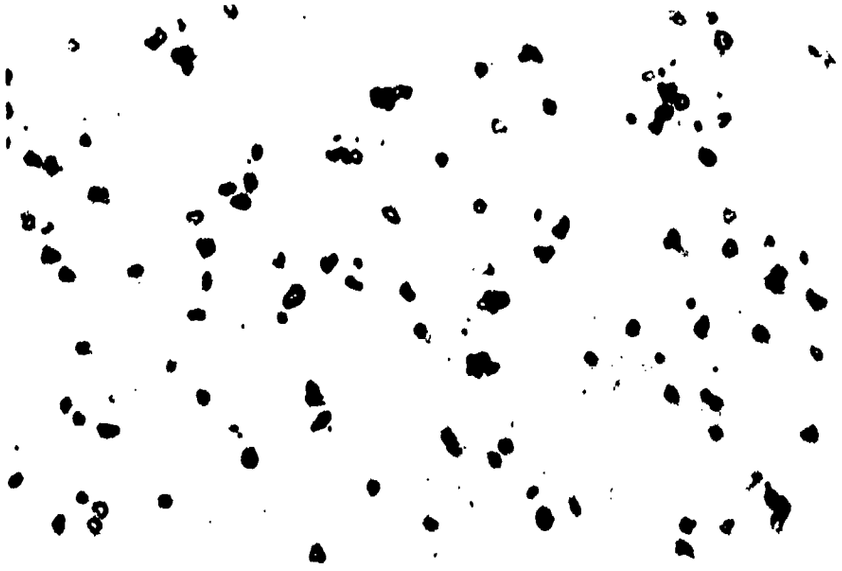


Figure 14. Particles collected at 7.19 ℓ/min., maximum equivalent diameter = 1.2 μm (1000X)

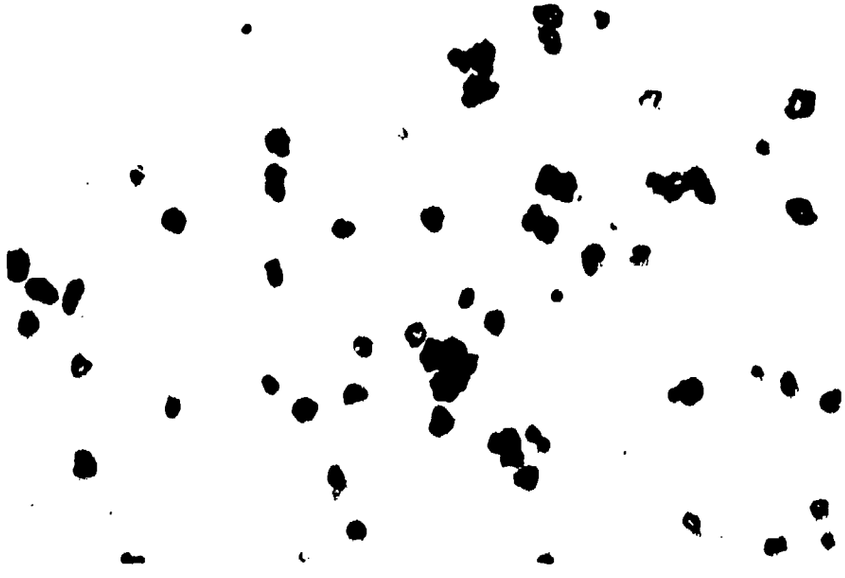


Figure 15. Particles collected at 3.60 ℓ/min., maximum equivalent diameter = 2.0 μm (1000X)

Figure 16. Particles collected at 2.40 ℓ/min., maximum equivalent diameter = 3.3 μm (1000X)

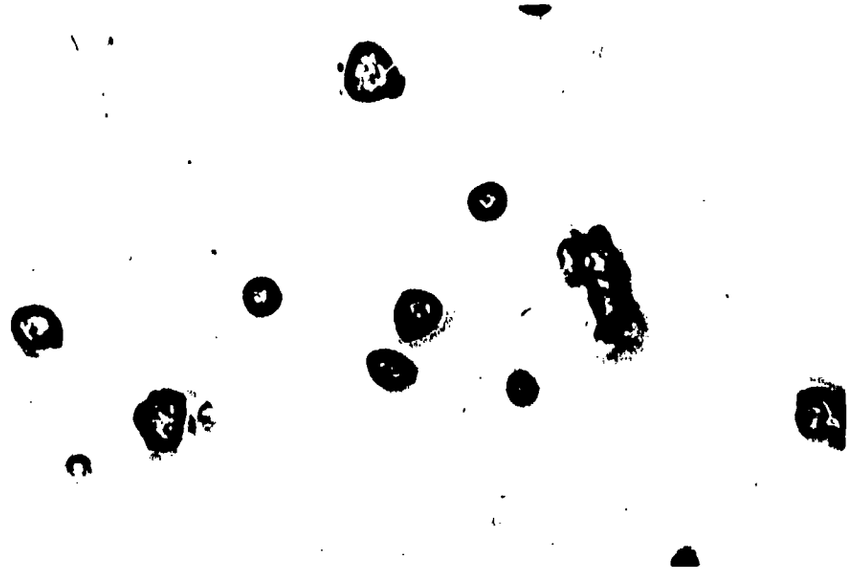


Figure 17. Particles collected at 1.47 ℓ/min., maximum equivalent diameter = 5.6 μm (1000X)

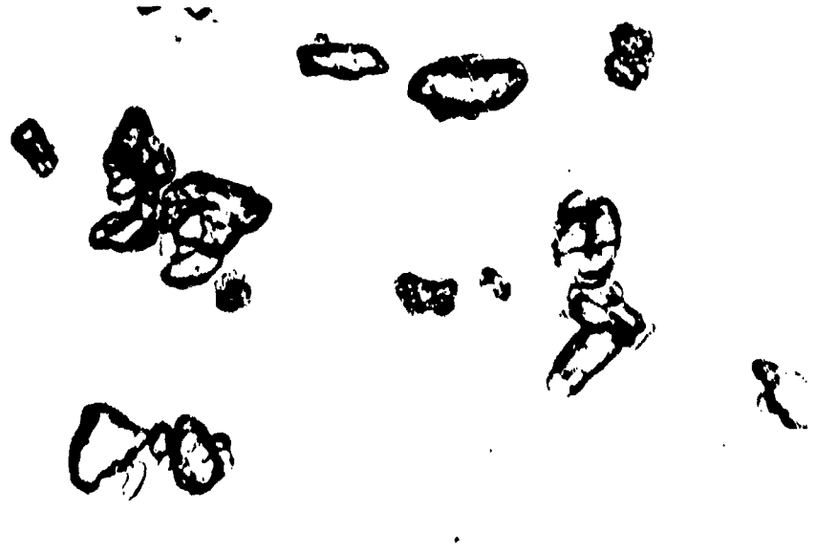


Figure 18. Particles collected at 0.03 ℓ/min., maximum equivalent diameter = 11.5 μm (1000X)

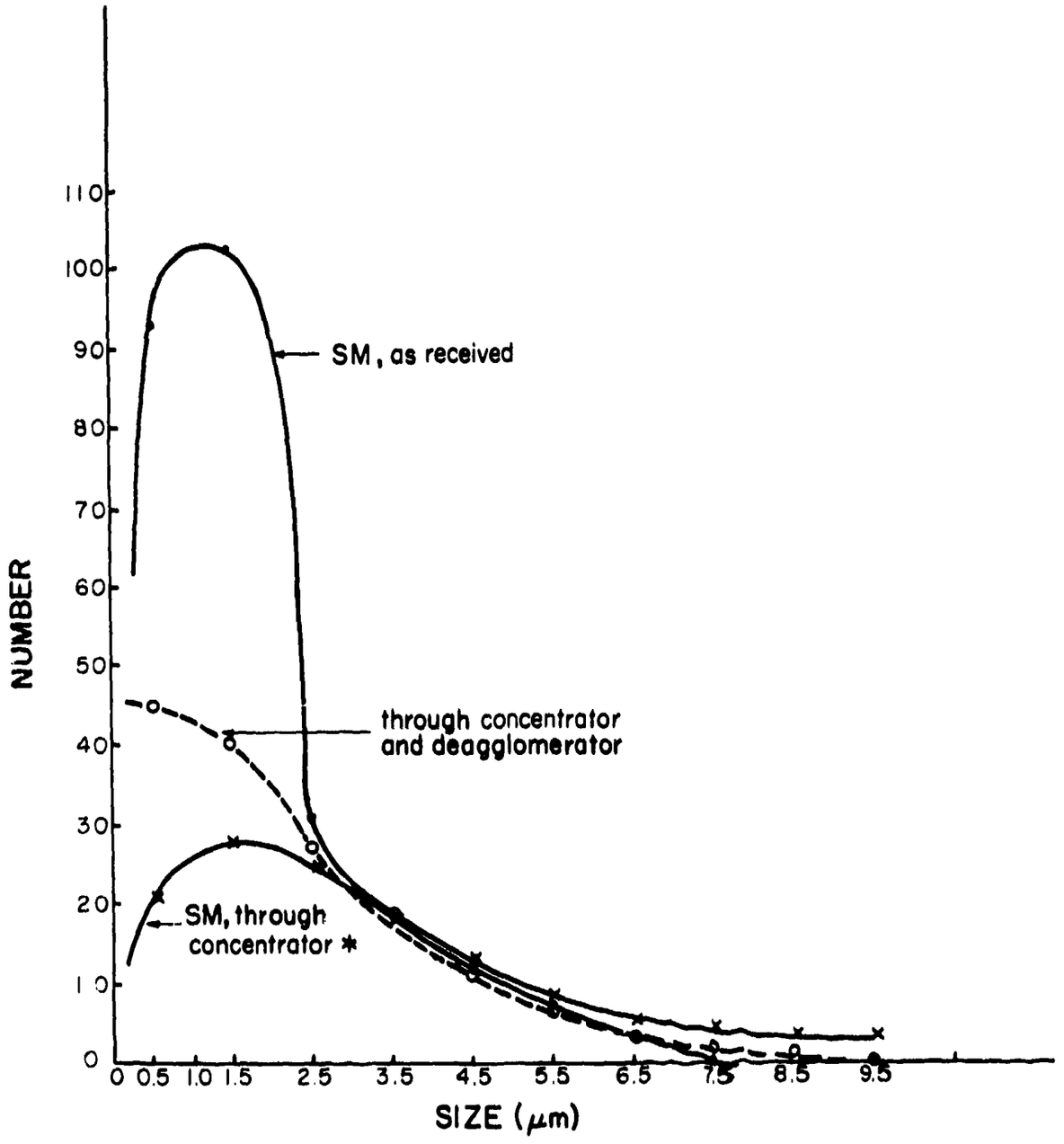
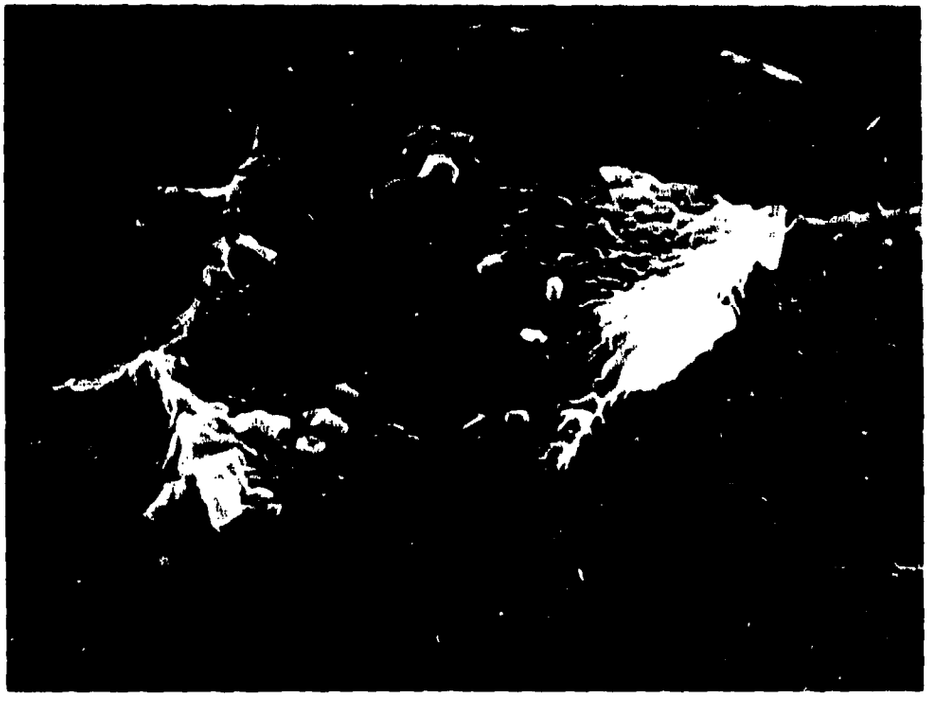


FIGURE 19. Particle size distribution of SM particles (normalized to same value at 3.5 μm for comparison).

Aerosol Concentrator *

(10,000X)



(5000X)

Figure 20-21. Scanning electron micrographs of typical aggregates of SM bacteria

FIGURE 22. Scanning electron micrograph of aggregate of nutrient material present in air suspensions of SM (10,000X)

FIGURE 23. Scanning electron micrograph of single SM particles deposited from a drying water drop (10,000X)

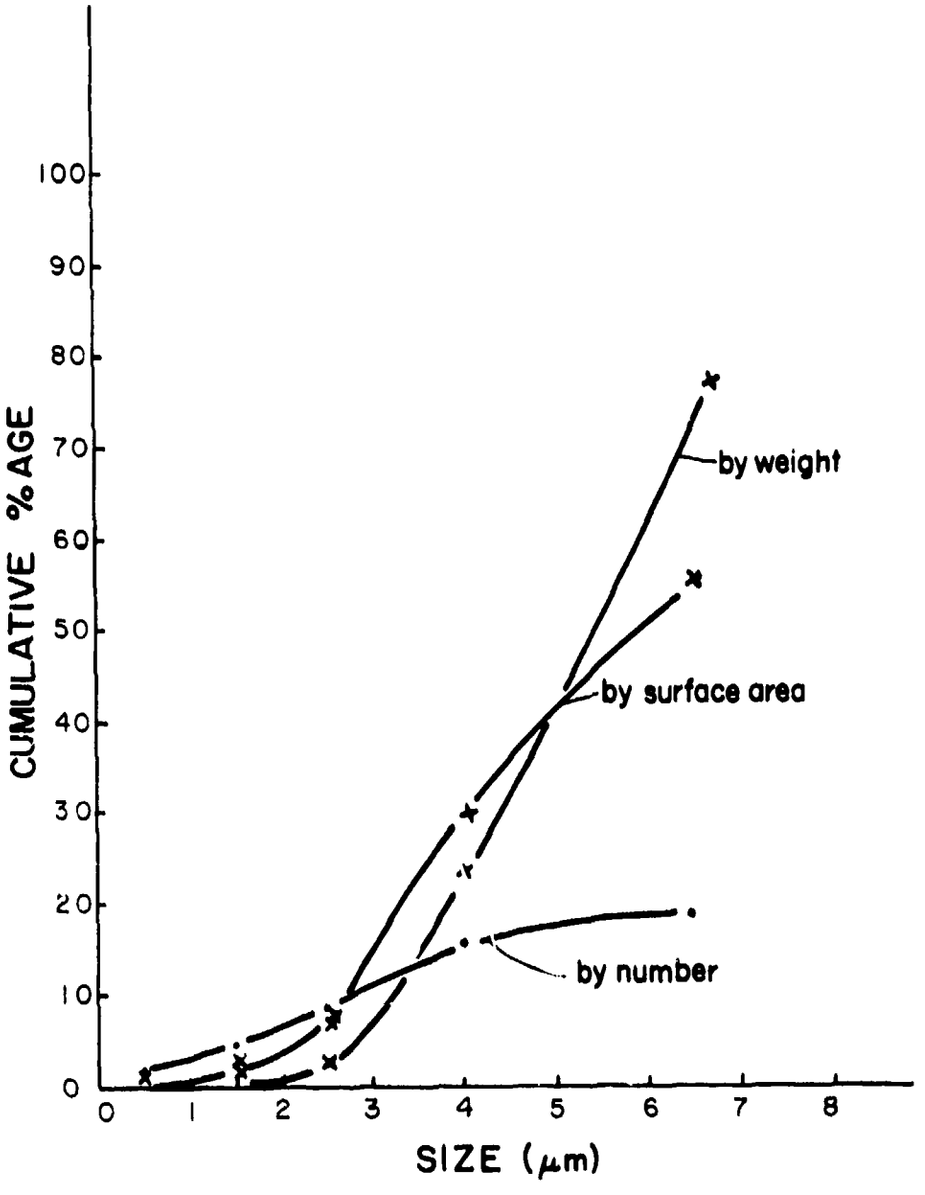
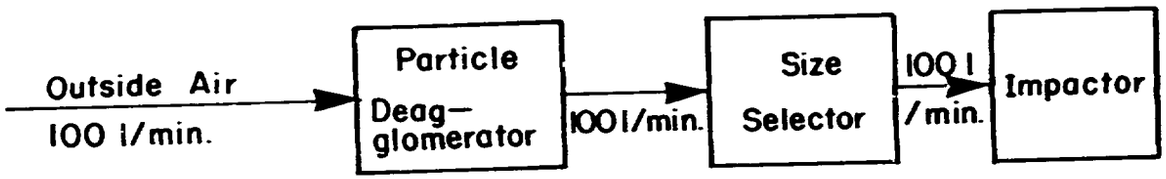
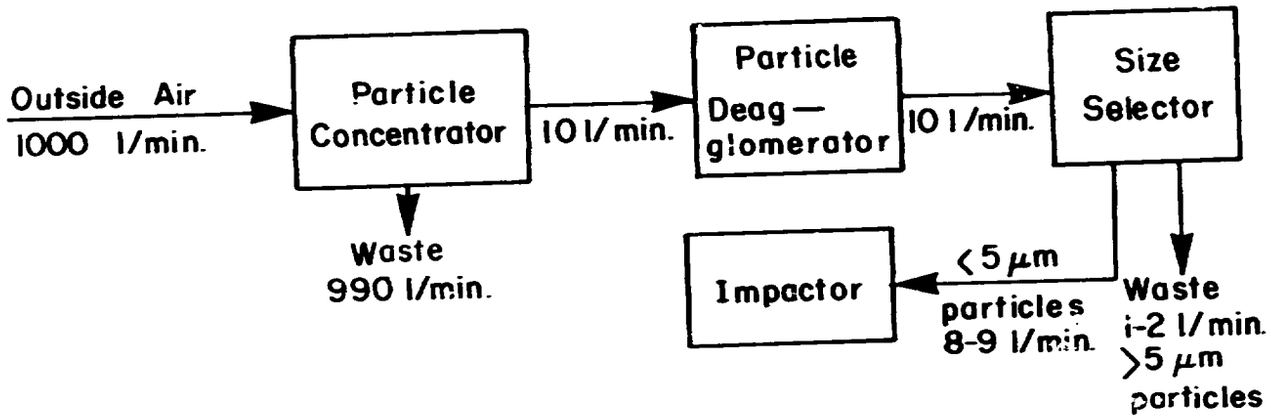


FIGURE 24. Cumulative percentages of SM particles delivered by the aerosol particle concentrator



a. without aerosol particle concentrator



• or cyclone

b. with aerosol particle concentrator

FIGURE 25. Two approaches to sampling the atmosphere for <5 μm particles

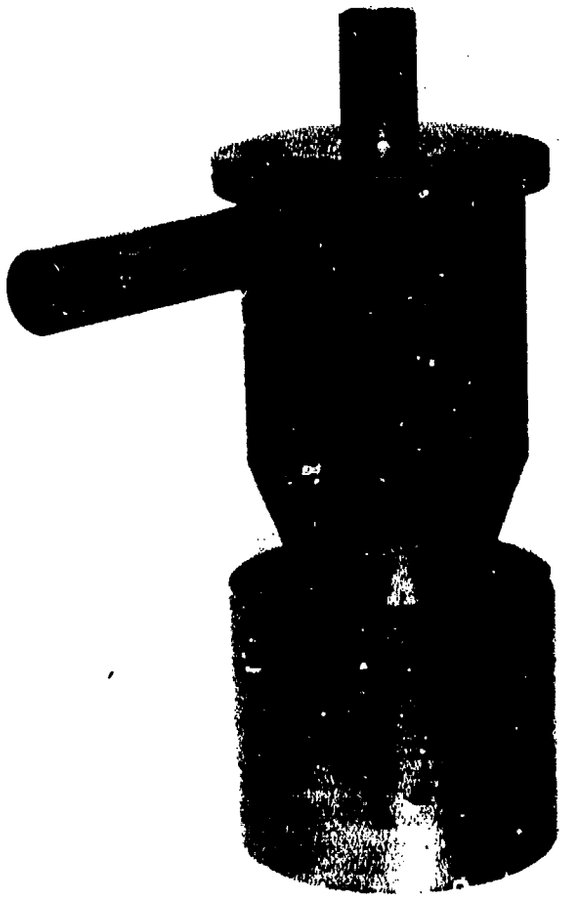
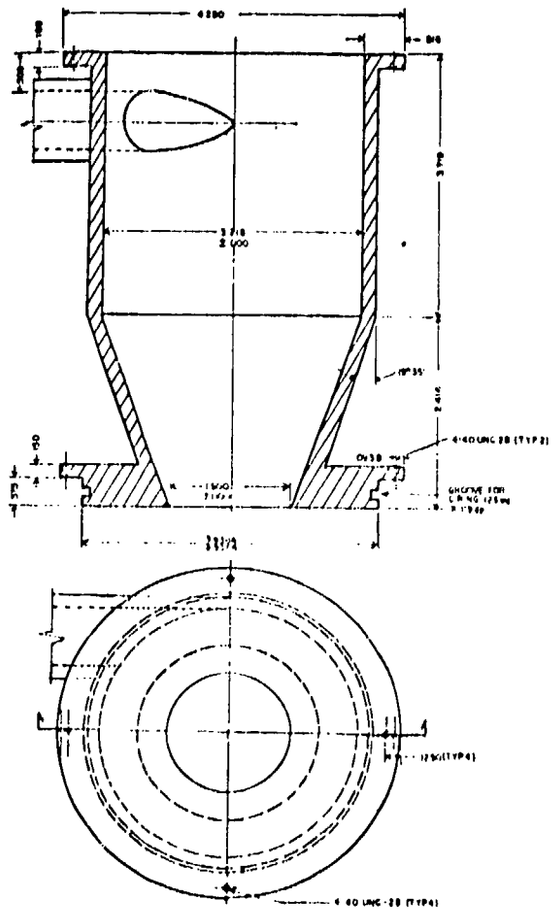
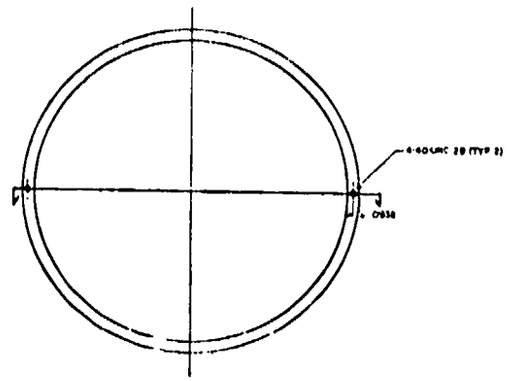


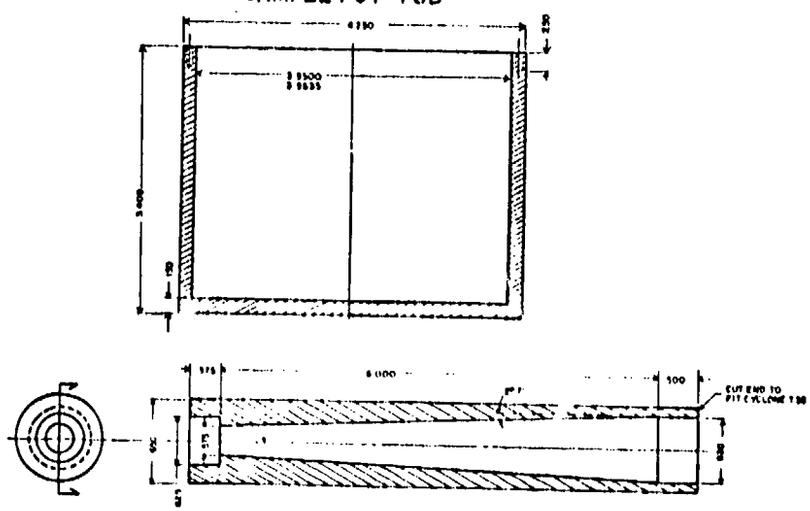
Figure 26. Upright view of T-3B cyclone separator



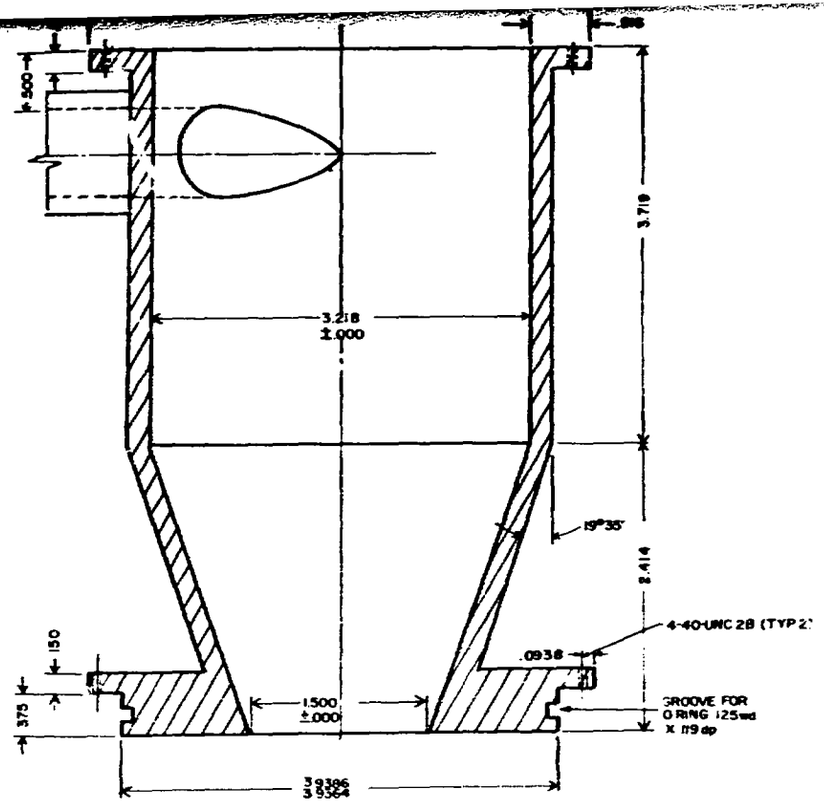
CYCLONE T-3B

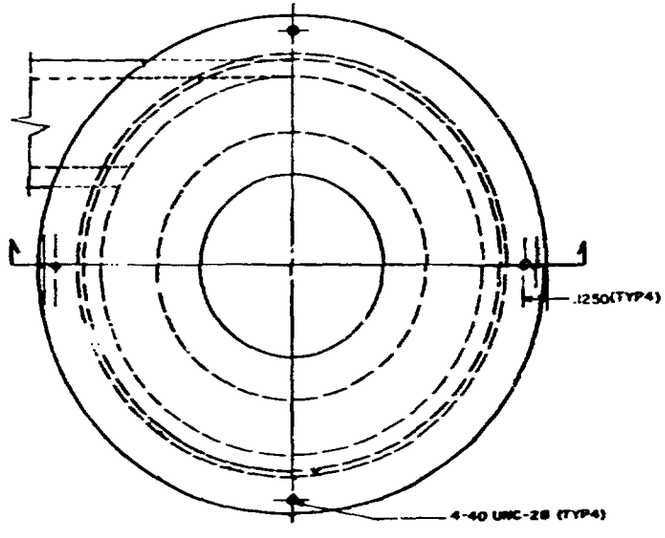


SAMPLE POT T-3B

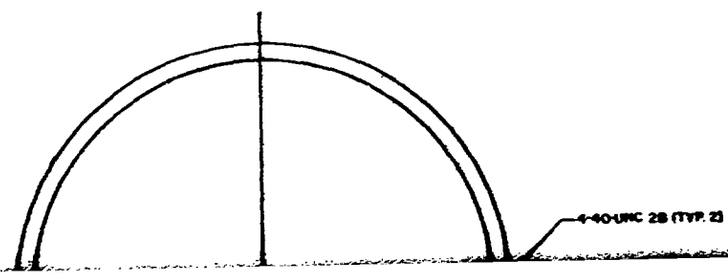


INLET PIPE FOR CYCLONE T 3B

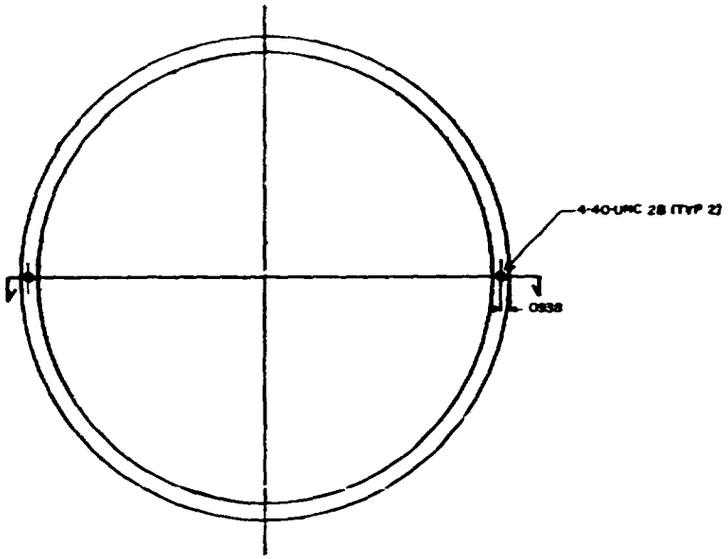

.500
3.719
3.218
±.000
19°35'
2.414
4-40-UNC 2B (TYP 2)
.0938
.150
.375
1.500
±.000
GROOVE FOR
O RING 125wd
X 119 dp
3.9386
3.9364


.1250(TYP4)
4-40 UNC-2B (TYP4)

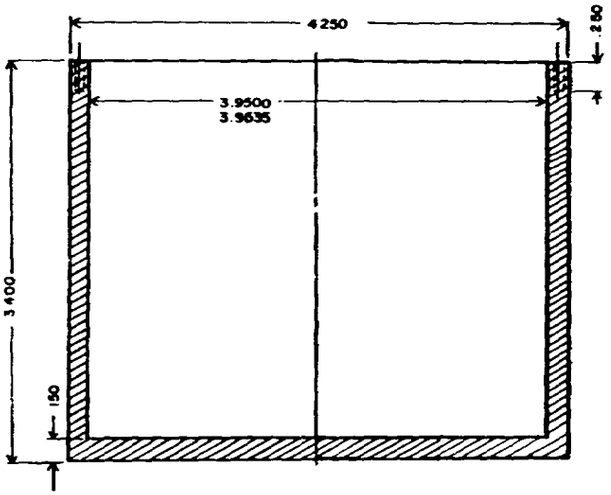
CYCLONE T-38

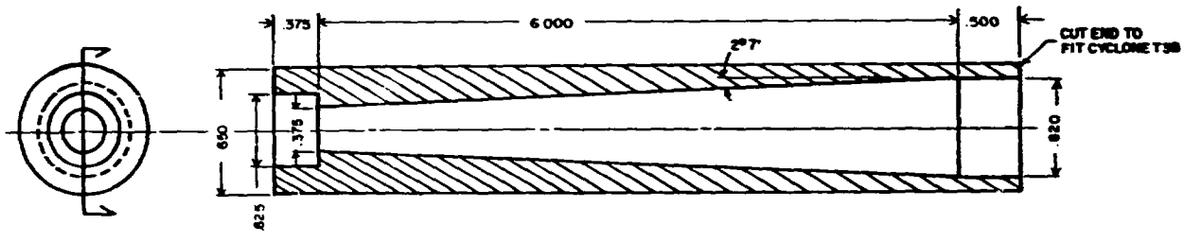

4-40-UNC 2B (TYP. 2)

CYCLONE T-3B



SAMPLE POT T-3B





INLET PIPE FOR CYCLONE T 3B

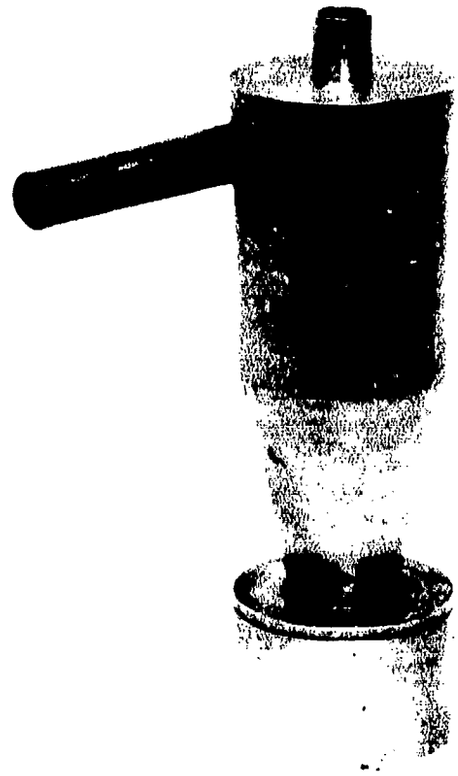


Figure 27. Upright view of cyclone T4

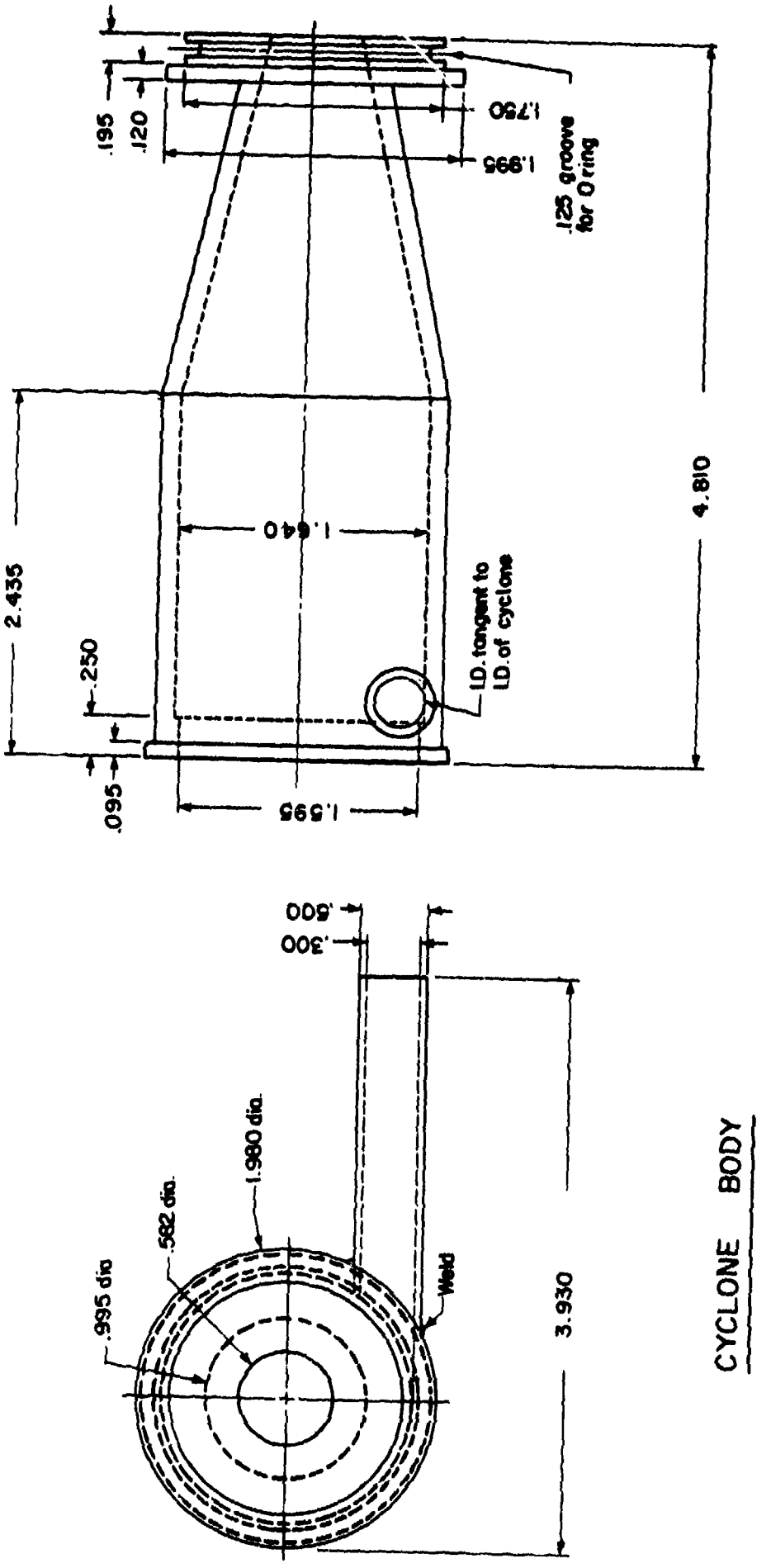


Figure 28. Shop drawings for cyclone T4

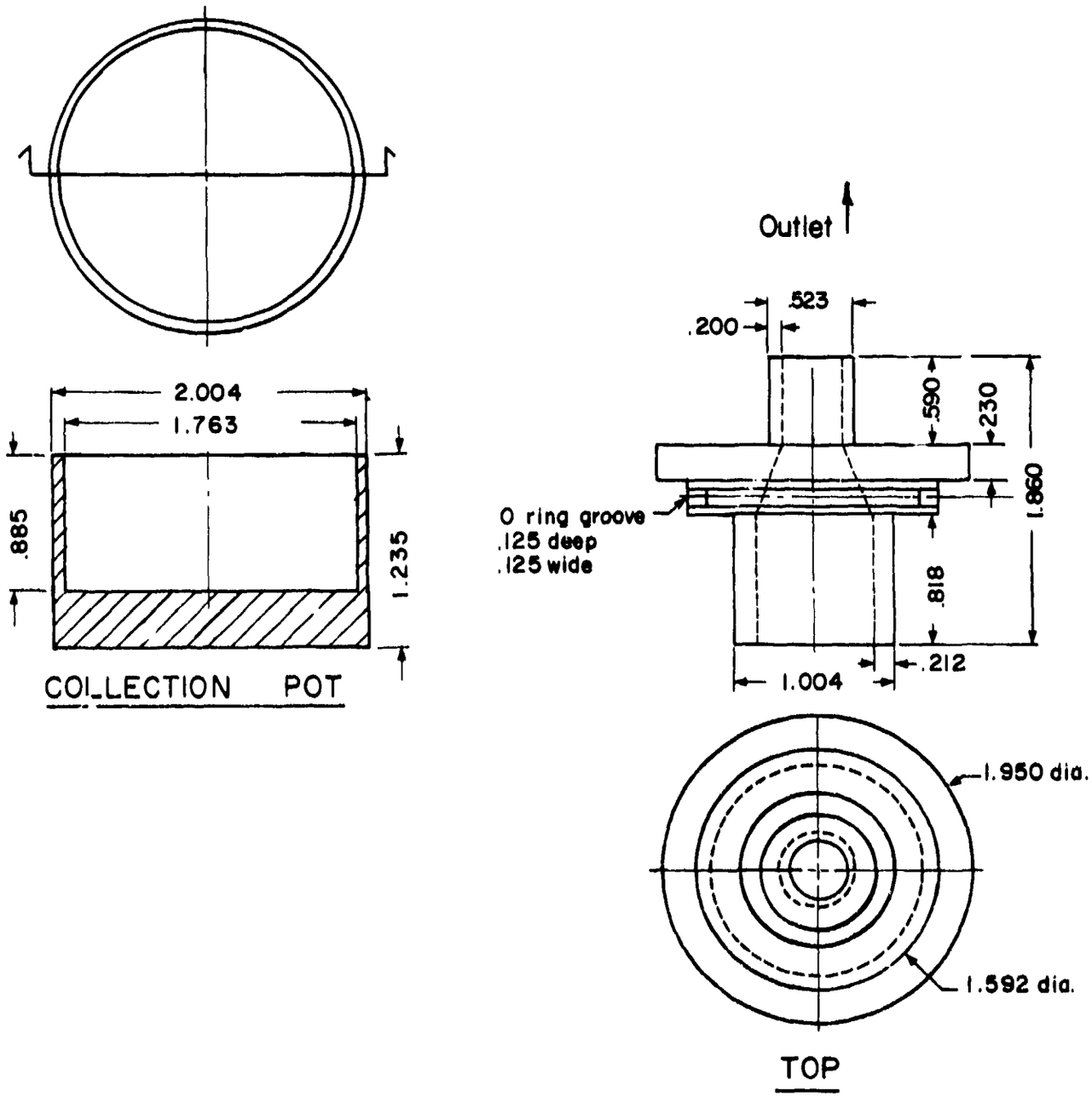


Figure 28. continued

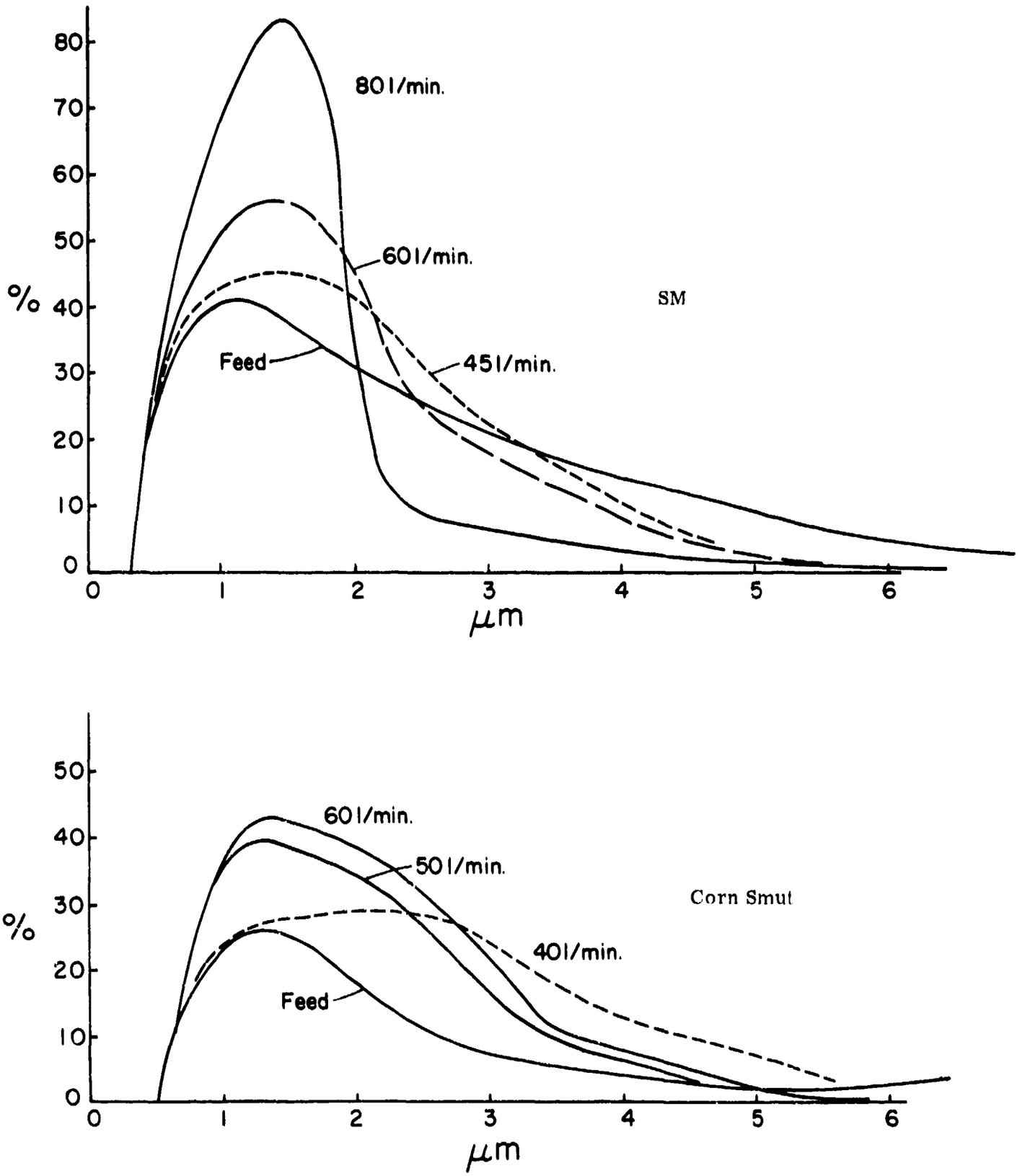


FIGURE 29. Performance of T4 cyclone with SM and corn smut particles

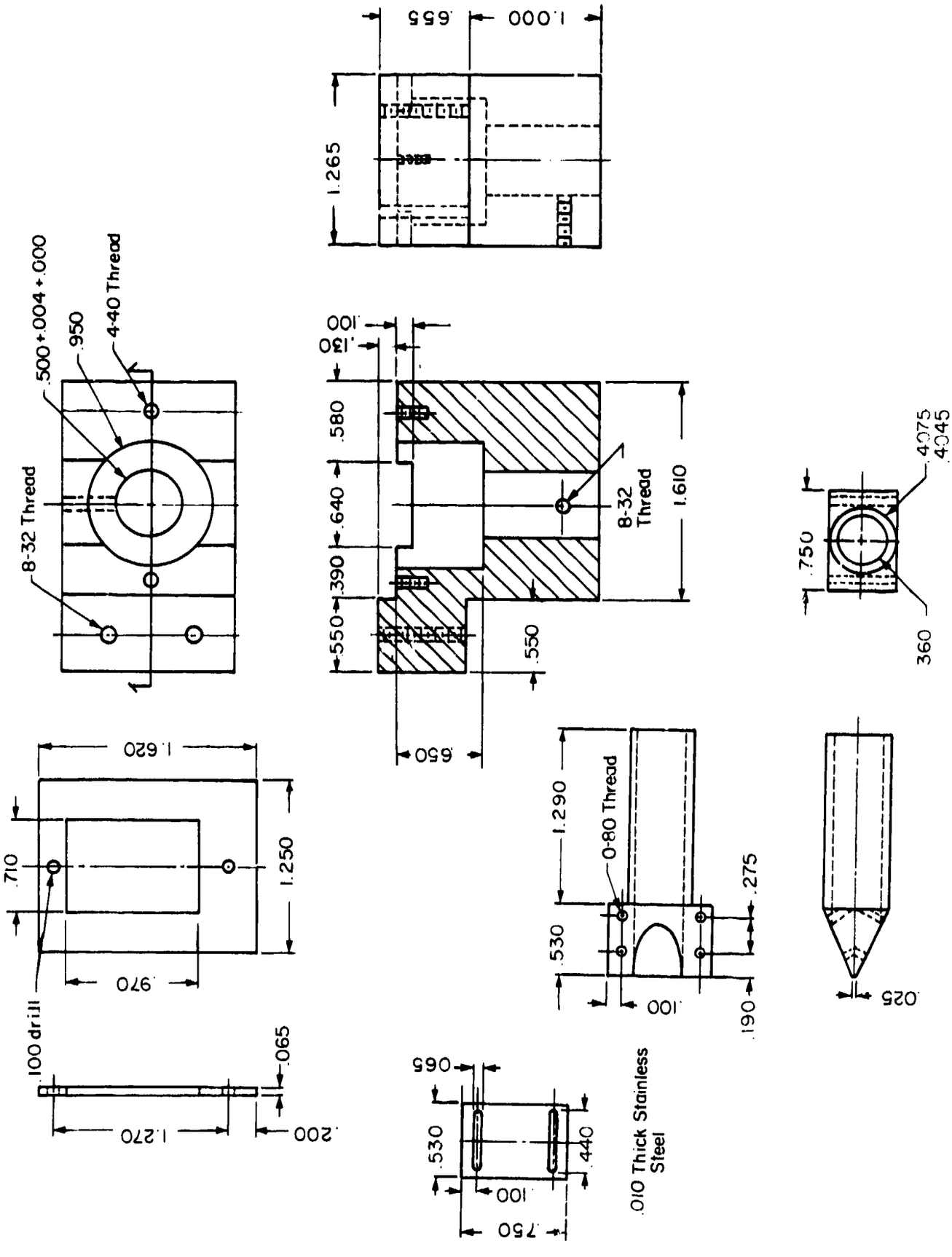
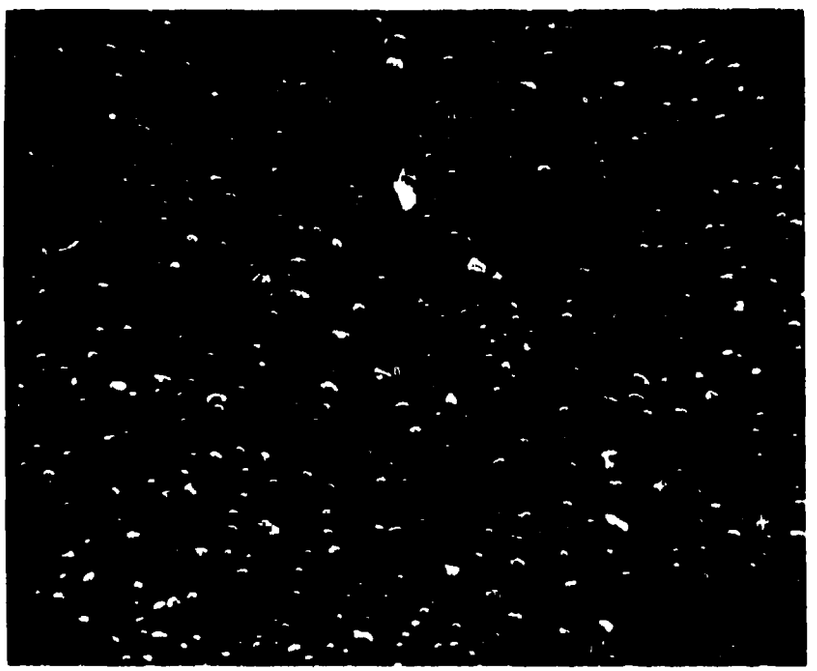
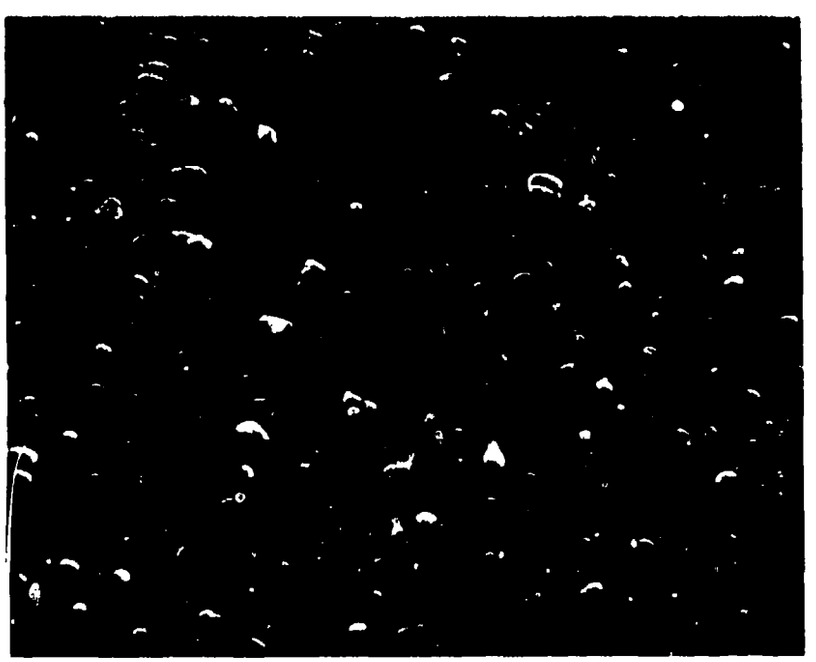


Figure 30 Block and Jet Assembly for Tape Impaction Using the T4 Cyclone



(500X)



(1000X)

Figure 31. SEM photomicrographs of SM particles